Author:
Stokes, Jessica Elizabeth

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Investigating novel and existing methods of preventing, detecting and treating digital dermatitis in dairy cattle

Investigating novel and existing methods of preventing, detecting and treating digital dermatitis in dairy cows

Jessica Elizabeth Stokes

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Look and you will find it - what is unsought will go undetected.

~Sophocles 68/365

In loving memory of Grandma and Grandad,

Beryl and Roger Pane.

Abstract

Digital dermatitis (DD) is a painful skin condition currently considered to be the leading cause of infectious lameness in dairy cattle. The overall objective of this project was to investigate novel and existing methods of detecting DD to be used by farmers and researchers to monitor the disease, and to investigate the impact of farmers' prevention and treatment strategies on disease prevalence.

Visual inspection of lesions in the parlour was found to be a practical and reliable method for detecting and classifying DD. In addition, thermography was identified as a potential tool for the detection of cattle foot disorders. Validating such methods for detecting DD is important because locomotion scoring alone was not found to be sufficiently sensitive to identify cows with DD. In a further study a novel ethogram approach validated several specific behaviours associated with DD.

A telephone survey was carried out to establish the nature and scope of management strategies farmers use to control DD. The two main strategies identified in the survey were 1) whole herd footbathing and 2) an individual treatment approach. A one year observational study on fifteen farms used the inspection method developed in the parlour to investigate the impact these two approaches had on disease prevalence. It was found that as herd size increased, footbathing became less effective in maintaining a low prevalence than treating cows individually.

Farmers use a variety of methods in an attempt to control DD on their farms, with different levels of emphasis placed on the priority and regularity of prevention and treatment. An outcome of this study is a DD monitoring approach farmers can use, to routinely assess the effectiveness of prevention and treatment strategies. In addition, results indicate that as herd size and disease prevalence increase, individual treatment is imperative for therapeutic resolution of DD.

Dedication and Acknowledgements

This body of work constitutes the output of my working life over the past three and half years and although the ultimate in solitary pursuits, a great debt of gratitude is owed to many people.

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Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of others, is indicated as such. Any views expressed in the dissertation are those of the author.

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Conference presentations

Stokes, J.E., Barker, Z., Bell, N., Bell, A.K., Maggs, C., Main, D.C.J. and Whay, H.R. Lameness in Dairy Cattle: Relationships between Environments, Animal Based Welfare Measures and Locomotion. *15th Symposium and 7th Conference on Lameness in Ruminants*, 9-13th June 2008, Kuopio, Finland.

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Chapter 1

Digital dermatitis in the context of the UK lameness problem

1.1 Causes and characteristics of lameness in dairy cattle

Lameness is characterised by a departure from normal locomotion, causing an observable deviation in gait. Greenough et al., (1981) defined lameness as a clinical sign of disease or abnormality of the muscular-skeletal system, which develops as a voluntary effort to reduce pain due to injury; or an involuntary mechanical impairment of gait due to damaged muscles, ligaments or nerves. Behaviour and motion is restricted as cattle attempt to reduce weight borne by an affected limb. It can therefore be seen as both an indicator and behavioural outcome of a specific or combination of diseases (Whay, 2002a).

Although lameness is predominantly assessed while a cow is in motion using locomotion scoring, it is frequently apparent when a cow is standing still, through lifting of affected limbs and reluctance to move (Whay, 1997). "Clinical lameness in cattle is a manifestation of pain, weakness, deformity, or musculoskeletal defect. It can be attributed to a multitude of causes, and in most cases is the end result of a complex interaction of anatomical, physiological, biomechanical, genetic, and management-related factors" (Vink, 2006).

The multifactorial pathogenesis of foot lesions makes cause and effect relationships difficult to determine (Sogstad et al., 2006). In over ninety percent of cases, lameness is caused by foot lesions, where inflammation or injury affects distal parts of the limb (Murray et al., 1996; O'Callaghan, 2002). The causes of lameness can be both infectious and non infectious. Specifically, the most common non infectious causes of lameness are sole ulcers, white line disease and sole haemorrhages (Murray et al., 1996). Bovine digital dermatitis (DD) is currently the most prominent infectious cause of lameness in the UK (Laven, 2003) and as such is the subject of this thesis.

1.1.1 Emergence and spread of digital dermatitis

Digital dermatitis was first described in Italy in 1974 (Cheli and Mortellaro). A few years later, Cornelisse et al., (1981) reported an outbreak in the Netherlands and it has since been reported in most other European countries (Kyllar et al., 1985; Roztocil et al., 1988; Bassett et al., 1990; Koniarova et al., 1993). It was first documented in the UK by Blowey (1987) and in the US by Rebhun et al., (1980). It now has a worldwide distribution, with a variety of forms being described across the continents, from North America (Canada: Hanna et al., 1994) to South America (Argentina: Rutter, 1989; Brazil: Borges et al., 1992; Mexico:

Argaez-Rodriguez et al., 1997; Chile: Rodriguez-Lainz et al., 1998) Africa (South Africa: Van Amstel et al., 1995), Asia (Japan: Kimura et al., 1993) and Oceania (Australia: McLennan and McKenzie, 1996).

Digital dermatitis is a painful infectious skin condition of cattle currently considered by veterinary surgeons and farmers to be the leading cause of infectious lameness in dairy cattle. It has been previously described as the main disease responsible for the failure of existing management strategies to reduce the prevalence and incidence of lameness in the U.K (Laven, 1999). Its rapid spread both within and between countries suggests a highly contagious nature. Over seventy percent of UK dairy farms were reported to be infected with the disease ten years ago (Whay, 2002b) with the incidence and prevalence continuing to rise (Vink, 2006). This highly infectious, prevalent and painful disease is a cause for serious welfare concern (Blowey, 1992; Murray et al., 2002).

1.1.2 Incidence and prevalence

Since being identified in the UK in 1987, DD has spread rapidly. Between 1989 and 1992, Murray et al., (1996) investigated the epidemiology of lameness across thirty seven farms across England and Wales. Digital dermatitis was the most commonly observed lesion affecting the distal parts of the skin, accounting for eight percent of lameness cases. Hedges et al., (2001) reported the disease as the third most prominent cause of lameness after white line disease and sole ulcers. More recently, Laven (2003) found that on seventy percent of farms surveyed, twenty five percent of all lameness cases were caused by DD. The author estimated the annual incidence at twelve in every one hundred cows. Whay et al., (2002b) found that seventy four percent of herds surveyed in the UK had DD. Herds affected by the disease had a significantly higher prevalence of lameness.

In the first cross sectional study carried out in the Netherlands, DD was identified in fourteen percent of cows (Frankena et al., 1991). Twenty years later Somers et al., (2003) found the prevalence had increased to thirty percent. In a further cross sectional study, Holzhauer et al., (2006) reported a mean prevalence of twenty one percent, ranging between naught and eighty three percent with only nine percent of 383 herds unaffected by the disease. Also in the Netherlands a herd with DD was monitored over a four week period for the presence and transition of lesions. Thirty six percent of cows were found to have active lesions on one hind claw, and eighteen percent had lesions on both claws (Holzhauer et al., 2007). These studies suggest that the prevalence of DD has rapidly increased over the past twenty years (Somers et al., 2003; Holzhauer et al., 2006).

1.1.3 Etiology and pathogenesis

Digital dermatitis involves complex, dynamic polymicrobial processes where mixed infections are common (Vink, 2006). The disease's contagious nature is evident in the rapid spread throughout herds and between countries and its behaviour suggests the infectious agent took advantage of predisposing conditions associated with large intensive dairy herds (Wells et al., 1999; Milinovich et al., 2004).

Digital dermatitis is a highly infectious skin disease with complex etiopathogenesis and multifactorial origin (Silva et al., 2005; Rodriguez-Lainz et al., 1996; Dopfer et al., 1997; Read and Walker, 1998b; Vink, 2006; Holzhauer et al., 2007). The precise aetiology of DD is unknown; it is currently thought to be passed from cow to cow (Carter et al., 2009) and the marked susceptibility of lesions to topical antibiotics (Britt et al., 1996) and presence of spirochetes suggest that bacteria play an important role in disease development (Read et al., 1992; Walker et al., 1995; Read et al., 1996). It is likely that a bacterial component is necessary for disease onset (Vink, 2006).

There is general consensus that the spirochetes found both superficially and in the deeper layers of the dermis are the predominant bacterial agent implicated in the infection. These have been identified as *Treponema* spp. (Blowey and Sharp, 1988; Read et al., 1992; Grund et al., 1995; Demirkan et al., 1998; Milinovich et al., 2004). It is evident that these spirochaetes are treponemes with a number of different phylotypes (Walker et al., 1995; Choi et al., 1997; Trott et al., 2003; Dhawi et al., 2005; Carter et al., 2009). More recently treponemes have been found in numerous hair follicles and sebaceous glands, suggesting a potential route of exit/entry for these pathogens (Carter et al., 2009).

Although histological investigations have implicated the involvement of *Treponema* spp. the difficulty of cultivating these organisms has meant that the fundamental understanding of aetiology, pathogenesis and epidemiology of the disease has yet to be explained. Little is known about the on farm distribution of *Treponema* spp (Vink, 2006). The only significant infection reservoir found in the farm environment is lesional tissue (Carter et al., 2009), implying cow to cow transfer of infection.

Difficulty in culturing lesions in healthy animals suggests that the pathogenesis of the disease is unlikely to be solely dependent on exposure to spirochetes. It has been suggested that infectious, environmental, farm-management and individual animal factors play a role in the disease pathogenesis (Rodriguez-Lainz, 1999). Read and Walker (1994) found that prolonged moisture and reduced access to air were necessary for successful transmission to calves using scrapings from active lesions. Anaerobic conditions of low oxygen and high moisture appear to be prerequisites for infection.

1.1.4 Epidemiology

A breach in biosecurity can introduce DD into a herd. This can occur by integrating infected replacement stock into a previously disease free herd (Rodriguez-Lainz et al., 1996; Wells et al., 1999). If infection is in a sub clinical stage and lesions are not present, and quarantine and treatment are not practiced, an epidemic outbreak can occur several weeks later (Vink, 2006).

Buying replacement heifers was associated with a five-fold increase in the prevalence of DD, compared to farms that were closed (Rodriguez-Lainz, 1996; Wells et al., 1999). Similarly, in Chile it was shown that farms that had bought in replacement heifers in the previous ten years were three times more likely to have the disease, compared to herds that did not buy in heifers (Rodriguez-Lainz, 1999).

Veterinarians and foot trimmers have also been implicated in the spread of DD within and between farms, due to a lack of cleaning and disinfecting equipment between treatments and visits (Wells et al., 1999).

In an initial outbreak, DD can spread rapidly through a herd, presenting a high prevalence of acute lesions. After exposure, the disease takes a more endemic course, where chronic lesions are present at a lower prevalence (Vink, 2006). There are no published reports of eradication of the disease from the farm environment once introduced. This suggests the reservoir of infection is maintained in the farm environment. The development of management protocols to control, and ideally eliminate the spread of the disease is urgently required (Laven and Logue, 2006; Vink, 2006).

1.1.5 Lesion presentation and location

Weaver et al., (1981) described DD as a diffuse or circumscribed superficial epidermitis of the digit at the coronary margin. The size of lesions varies enormously (< 1cm to > 6cm) and they are characterised by an irregular demarked circular area. The shape of lesions can also vary depending on location (Vink, 2006). Although lesions can be seen all around the coronary margin (Weaver et al., 1981), they are most commonly present on the plantar aspect of the rear foot, affecting the skin adjacent to the interdigital cleft or the skin-horn junction, midway between the heel bulbs (Rebhun et al., 1980; Cornelisse et al., 1981; Blowey and Sharp, 1988; Holzhauer et al., 2007). Less frequently lesions are found adjacent to the dew claws or bordering the dorsal interdigital cleft (Blowey and Sharp, 1988). It is estimated that approximately eighty to ninety percent of lesions occur in the hind feet (Nutter and Moffitt, 1990).

Digital dermatitis is a dynamic disease. There can be a substantial degree of variation in disease presentation. Lesions at different stages of development are often present on the same foot (Dopfer et al., 1997). New lesions can develop after regression of a previous lesion (Vink, 2006) due to re infection. Berry et al., 1999 found that 60% of successfully treated cows may develop recurrent lesions between seven and fifteen weeks later, suggesting that if immunity to the disease develops, it may be incomplete or temporary.

A significant proportion of cows also have lesions on both hind feet. Laven (2001) found that sixty three percent of an endemically affected herd in the UK had lesions on both hind feet. In the Netherlands Holzhauer et al., (2006) found thirty percent of cows with digital dermatitis presented active lesions on both hind feet.

1.1.6 Lesion classification and stages of development

The presentation of lesions changes as the infection develops, and can be used to indicate the clinical disease state. However, no internationally recognised system currently exists for identifying and classifying the stages of disease progression. Research in different countries has classified the development of lesions using different methods, reflecting different stages and/or manifestations of the disease (Dopfer et al., 1997; Laven, 2001; Vink, 2006). The two most widely cited and recently developed systems are described here. Both suggest four stages of disease development. Dopfer et al., (1994) developed a standard scoring system in the Netherlands which has since been adopted by several researchers (Dopfer et al., 1997; Holzhauer et al., 2007). In the absence of a gold standard, Dopfer (1994) recommended the need for a repeatable universal classification system. Recently, Vink (2006) developed a similar four stage system integrating literature in the UK and clinical presentation of the disease on farm.

Using the Dopfer et al., (1994) scoring system stage naught is recorded for feet with normal digital skin free from lesions during macroscopic inspection. A lesion in stage one of the disease is characterised by a circumscribed granulomatous area described by Dopfer et al., (1994) as non painful, and typically 0.5 to 4 cm in diameter. Stage two is the classical ulcerative stage of granulomatous tissue which can reach 7 cm in diameter. Lesions at stage three (M3) are classical ulcerative lesions in the process of healing covered by a scab and stage four (M4) is a chronic stage characterised by proliferation of the surface that is generally not painful. While stage two and four are considered to be the most infectious stages of digital dermatitis, stage two is considered to be the most painful (Dopfer et al., 1997; Holzhauer et al., 2007).

Recently, Vink (2006) developed a four stage scoring system based on clinical presentation in the UK. Stage one presents as matting of superficial hairs of the affected digital skin coupled with wet eczema developing into an erosive lesion (Mortellaro et al., 1985). Several researchers have reported an elevated level of altered tissue at this stage (Read & Walker, 1998), however usually the lesion is flat or lower than the skin surface level. Erosive lesions are prone to bleeding, moist and red in colour (Walker, 1995). Lesions at this stage are very small but are reported to be intensely painful (Vink, 2006).

Stage two describes a granulomatous lesion. Lesions at this stage are demarcated by borders with growth of keratin pins on the surface of the erosions, where the lesion appears stippled and 'strawberry like' (Cornelisse et al., 1981). As keratinisation progresses lesion size increases. Lesions at this stage have a distinctive odour (Cornelisse et al., 1981) but do not bleed and are usually covered in grey debris (Blowey and Sharp, 1988).

Stage three describes a proliferative lesion, characterised by progressive hyperkeratosis. The keratin pins at this stage proliferate and become several centimetres long. Lesions become prominent with a demarcated border and typically long hairs grow around the lesion.

Stage four is a lesion which after treatment regresses into a dark, rubbery, firm scab (Dopfer et al., 1997). It will depend on what stage the lesion was treated as to the presentation of the skin underneath. Smooth or scarred skin indicates the completion of infection, however hyperkeratotic skin may suggest that regression is superficial. In this case reactivation of the lesion(s) can occur.

1.1.7 Existing methods of detecting digital dermatitis

A reliable method for determining the presence, stage and severity of DD is required in order to monitor the effectiveness of management strategies over time. The method criteria may differ depending on its purpose. For example, farmers require a method which is practical and feasible for routine disease detection and treatment. Researchers may also require a reliable, repeatable method for monitoring the success of treatment intervention over time. Traditionally, lesion detection is carried out by visual inspection of the lifted foot in the crush (Blowey and& Sharp. 1988; Blowey, 1992; Murray et al. 1996; Murray et al. 2002; Vink, 2006). However, this method is too time, labour and cost intensive to be employed as a routine method of detection.

Research has therefore focussed on developing methods of disease detection without having to lift the foot. The approach most widely adopted in practice is to squat down behind the cow and illuminate the plantar area of the foot. However, early lesions are often small, and where the cows' feet are covered in dirt and manure, it has been suggested that lesions may be missed resulting in an under recording of disease prevalence (Vink, 2006).

Thomsen et al. (2008) investigated a rapid screening method involving a fifteen seconds per cow observation period carried out from the pit in the milking parlour. This study used three test herds and found a sensitivity of 0.65 (95% confidence interval: 0.59 to 0.72) and specificity of 0.84 (95% confidence interval: 0.81 to 0.87) in the parlour compared to a 'gold standard' inspection in the crush. Laven (1999) validated the use of a modified scope (Borescope) against a lifted foot inspection in the crush and reported individual lesion specificity of 0.84, and sensitivity of 0.82. The technique was then subsequently adopted in several research contexts (Laven and Proven, 2001; Vink, 2006). However, the reliability of lesion inspection in the milking parlour has not been compared with the Borescope.

The first body of work presented in this thesis investigated novel and existing methods of visually detecting DD. Chapter two describes a study which aimed to identify a practical and efficient means of scoring the prevalence and severity of DD in a whole herd on a routine basis. When developing a method of disease detection, it is necessary to assess reliability. This study evaluated and compared three examination methods for DD (parlour, Borescope and lifted foot) in terms of their sensitivity and specificity of detection, and the agreement between them achieved when assessing lesion characteristics.

1.1.8 Novel methods of digital dermatitis detection

Early detection of disease is the first step towards successful treatment intervention. Infrared thermography (IRT) is a non invasive quantitative assessment of temperature. Infrared thermography gives a pictorial representation of the surface temperature of an object (Purohit and McCoy, 1980; Turner et al., 1986) where the colour gradient reflects differences in emitted heat. Heat is a cardinal sign of inflammation, illustrating an increase in circulation and tissue metabolism (Head and Dyson, 2001; Van Hoogmoed and Snyder, 2002). Monitoring temperature fluctuation can therefore indicate development of inflammation in tissues. Infrared thermography may therefore have the potential to identify feet with an infectious disease such as DD without having to lift or clean the foot. Chapter three examines the potential of IRT as a non invasive tool for rapidly screening cows for the presence of DD.

1.1.9 Lameness and digital dermatitis

Cows with DD are commonly seen walking on their toes to shift weight away from the lesion site (Blowey and Sharp, 1988; Read and Walker, 1998). Other typical behaviours include shaking of the affected foot and shifting weight from one leg to another (Bassett et al., 1990). However, it is important to note that in many cases the presence of a lesion is not accompanied by obvious lameness (Vink, 2006). Laven and Proven (2000) found that although ninety percent of cows showed a pain response when light pressure was applied to a lesion, only twenty seven percent of these cows were scored lame. Ettema et al., (2009) modelled the relationship between disease prevalence and locomotion score and found that DD had a low probability of resulting in lameness compared to claw horn lesions such as sole ulcers and white line disease. This suggests that locomotion scoring maybe insufficient for identifying cases of DD. Where locomotion scoring is the only outcome measure for detecting cases for treatment and footbathing treatment is not implemented, DD cases can persist undetected and untreated. To apply appropriate intervention strategies to control the disease, establishing the disease status of each cow and herd level prevalence is essential. In order to establish whether a scoring system is appropriate, it is necessary to identify patterns of lameness behaviour associated with specific diseases. The reliability of using a locomotion scoring system to detect DD and other behavioural indicators is presented in chapter four.

1.1.10 Behaviour and welfare

Avoidance of full weight bearing on one or more limbs can be an expression of pain and discomfort indicating suffering. Somers et al., (2004) investigated the effect DD has on cows' locomotion and behaviour. It was found that severely affected cows stood for longer in cubicles, and had a reduced total lying time compared to cows with no foot lesions. The discomfort or pain associated with the disease can reduce cow mobility and lying behaviour.

This has consequences for welfare and production. Reduced mobility can lead to reduced visits to the feed rail and a reduction in lying behaviour can disrupt digestion as cows prefer to ruminate lying down (Cooper et al., 2007). A disruption to lying behaviour can also have consequences for social behaviour and hierarchy (Fregonesi and Leaver, 2001). Restricted mobility reduces the physical and social interaction between the cow and her environment directly infringing on welfare (Galindo and Broom, 2000).Research has indicated that DD can impact on several aspects of the cows' behaviour. Locomotion scoring is currently used as the outcome measure for identifying claw lesions and draws on several aspects of behavioural compensation as an indicator of disease. However it was developed as a generic tool, and may not focus on behaviours related to a specific infectious disease such as DD. Research has suggested that DD is not always accompanied by obvious lameness (Laven and Proven, 2000; Vink, 2006). Behavioural changes appropriate to DD have the potential to be used as indicators of disease presence. An ethogram was developed to assess whether the presence of disease was associated with specific abnormal behaviour(s). The results of this study are presented in chapter four.

1.2 Risk factors for digital dermatitis

The causal mechanisms of DD are not clearly understood, but on farm the disease is dynamic and multifactorial with the prevalence within and between farms varying greatly (Somers et al., 2003; Holzhauer et al., 2006). Numerous risk factors have been reported in the research literature. The primary emphasis in previous studies has been to investigate broad environment, management and production factors which have been associated with an increased prevalence of the disease. Research has focused on herd level risk factors (Frankena et al., 1993; Argaez Rodriguez et al., 1997; Wells et al., 1999; Bell, 2006; Cramer et al., 2008; Barker et al., 2010). However it is factors at the individual cow level that determines why some cows develop the disease and others appear unaffected in a similar environment (Laven and Logue, 2006).

1.2.1 Environmental risk factors for digital dermatitis

An increased prevalence of DD during the winter housing period is associated with poor environmental hygiene (Vink, 2006; Bell, 2006). Restricted grazing is a risk factor for DD compared to a full grazing system (Somers et al., 2005a). The prevalence of the disease increases the longer the cows are housed; Somers et al., 2005a found that cows housed for more than seventy five days were twice as likely to develop the disease, compared to cows housed for less than twenty five days.

Although DD is at its worst during winter, it is no longer considered a disease of the housing period only (Vink, 2006). It has become an endemic disease with new cases developing and recurring throughout the year (Laven and Lawrence, 2006). Bell et al., (2009) reported a prevalence of thirty two percent in spring, thirty six percent in autumn and forty eight percent in winter across sixty farms in 2003.

The management of the housing system can have a significant impact on the prevalence of DD. Poor foot hygiene and wet conditions where the feet are continuously exposed to an anaerobic environment have long been implicated as significant predisposing factors for the disease (Frankena et al., 1993; Rodriguez-Lainz et al., 1996). Poor cubicle design has also been associated with an increased DD prevalence (Somers, 2004). Poor quality walking surfaces and tracks can cause and exacerbate trauma to the foot and excessive hoof wear (Blowey, 2005; Bell et al., 2009). Prolonged contact with slurry and faecal ammonia can cause the skin barrier to soften, becoming more susceptible to abrasion and invasion by micro organisms (Vink, 2006).

In the US, Rodriguez-Lainz (1996) found that the likelihood of cows being affected by DD was twenty times greater in herds with dirty passageways, compared with farms that had drier, cleaner passageways. In the Netherlands, Somers et al., (2005b) found that cows kept on a slatted floor with a scraper were at lower risk from developing the disease. The authors attributed this to a reduced exposure to anaerobic conditions.

Laven (1999) found the prevalence of DD was significantly higher among cows in automatically scraped cubicle housing, to cubicle housing scraped by tractor. This was attributed to cows walking through the slurry build up associated with automatic scraping systems. Similarly, the risk of DD was lower for cows housed on a slatted floor with a manual scraper, and those provided with long and wide cubicles (Somers et al., 2005a). Furthermore, cows housed in cubicles were one and a half times more likely to develop lesions, compared with those kept on straw yards. Housing cows on straw yards decreased both the severity and prevalence of the disease (Somers et al., 2005a).

The emergence of an apparently closely related ovine strain of bovine DD has suggested the potential for cross-species transmission. The presence of genetically related treponemes in ovine foot rot and bovine DD means there is a need to establish whether cograzing, which is common in the UK, may be a risk factor in transmission between cattle and sheep (Collighan et al., 2000). Similar organisms have also been isolated from contagious ovine DD (Dhawi et al., 2004). A recent study has identified that cows grazed on pasture also grazed by sheep were at significantly increased risk of lameness (Barker et al., 2010).

Herd size has also been identified as a risk factor for the disease (Frankena et al., 1991; Rodriguez-Lainz et al., 1996; 1999). Holzhauer et al., (2006) found that cows in smaller herds (< 45 cows) were at lower risk from being affected by DD than cows in medium and large herds (60-85 cows). More recently, Ettema et al., (2009) modelled the probability of increased prevalence of disease and found that a herd size above 125 cows significantly increased the probability of DD.

Digital dermatitis prevalence can also be increased through lack of prompt treatment, poor foot care (either through infrequent trimming, bad technique or not disinfecting foot trimming equipment between cows and herds (Wells et al., 1999)), insufficient time spent observing lame cows, lack of awareness and identification of individual cases (Whay et al., 2002a), and ineffective or too infrequent individual or herd level treatment intervention. For example, not using footbaths or non-regular use of footbaths was associated with higher prevalence of digital dermatitis compared to regular use of footbaths (Ettema et al., 2009). Chapter six models the impact of herd size and treatment strategy on the prevalence of the disease over the period of one year.

1.2.2 Cow level risk factors for digital dermatitis

The importance of the cow as a risk factor for DD has been relatively under studied despite the suggestion that individual cow factors play an important role in the development and progression of the disease (Laven and Logue, 2006; Vink, 2006). Previous studies have suggested that not all cows are equal regarding their risk of recurrent infections and prospect of curing from DD (Nielsen et al., 2011).

A recent study investigated host heterogeneity to DD in 742 cows on three commercial dairy farms in Denmark (Nielsen et al., 2011). It was found that early lactation was associated with a reduced risk of developing DD; however lesions that developed in late lactation were more likely to recover. Cows in parity three had a reduced risk of DD compared to cows in parity one, whereas cows in parity two had an increased risk of DD (Nielsen et al., 2011).

Individual foot and body hygiene scores have been incorporated into on farm risk assessments for the disease. Vink (2006) found that foot and body hygiene scores were a significant risk factor for the presence of DD lesions. In a recent study, the impact of hygiene score on DD score in 2932 cows was assessed (Nowrouzian and Radgohar, 2011). Hygiene scores for the lower part of the hind limbs were significantly associated with DD prevalence, where DD increasing as hygiene scores increased.

The importance of maintaining good foot conformation has been identified in several studies. Somers et al., (2005a) found that an interval of more than seven months between trimming cows feet was associated with DD, compared with regular foot trimming. Shallow heel heights lead to a greater exposure to anaerobic foot conditions, potentially increasing the cow's exposure to infection (Vink, 2006).

The Holstein-Friesian breed is significantly more likely to develop DD lesions than other dairy and beef breeds (Frankena et al., 1991; Rodriguez-Lainz et al., 1999; Holzhauer et al., 2006). Brown et al., (2000) found lesions in the hind feet of twenty nine percent of dairy cattle, compared with four percent of beef cattle.

1.2.3 Herd risk factors for digital dermatitis

Introducing dry cows into the lactating herd before calving is associated with DD (OR 2.7 for ≤ 14 days before calving, and 1.8 for > 14 days) relative to introducing immediately after calving (Somers, 2004). However the risk is significantly reduced if calves are reared in the cows housing (Somers et al., 2005a). Dry cows were found to be at lower risk of developing lesions in several studies (Murray et al., 2002; Somers et al., 2005a). This effect can be maximised by avoiding contact with lactating cows before calving (Somers, 2004). Dry cows have a higher proportion of roughage in their diet which results in less exposure to wet and unhygienic flooring conditions caused by liquid slurry in lactating cows (Somers et al., 2005a). An increase in concentrate around the time of calving was strongly associated with DD (Somers et al., 2005a).

1.3 The economic impact of digital dermatitis

Traditionally research has focussed on quantifying the costs of lameness, without examining the costs of specific pathologies. An accurate estimate of the cost of DD within and across farms is difficult to establish as lameness cases are often associated with multiple pathologies, and have many "hidden" indirect costs. For example, many farmers treat all cows at a herd level when only a proportion of the herd is affected at any one time. Here farmers use a range of whole herd preventative treatments as well as individual treatment, making the cost of a single case difficult to calculate. The costs of treatment, time and labour, as well as the impact on production in terms of reduced milk yield and fertility is considerable (Hernandez et al., 2002, Cha et al., 2010).

More recently researchers have begun to quantify the economic impact of the disease specifically. Milk yield has been found to be both an important effect of DD but also a risk factor (Green et al., 2002; Ettema et al., 2007). Green et al., 2010 found that cows with DD had a significantly higher milk yield compared to unaffected cows for the whole lactation, where a dip in yield one month before treatment is seen. Milk yield increased in the month after treatment. This suggests that higher yielding cows may be more susceptible to the disease (Green et al., 2010).

To enable farmers to make informed decisions about treatment, economic costing at an individual cow level is essential. A recent study modelled the cost of DD at an individual cow level (Cha et al., 2010). The cost was estimated at £133 per case. Treatment cost was the main component of the total cost (42%), followed by the effect on fertility (31%) and milk loss (27%). The authors recommend that in 95.5% of cases the disease should be treated (Cha et al., 2010).

1.4 Prevention and Treatment

Prevention of DD relies on etiological and pathological understanding of the disease which has yet to be determined. To date, risk factor studies have focussed on management factors associated with increased disease prevalence (Bell, 2006; Cramer et al., 2008; Barker et al., 2010). Reducing risks such as quarantining bought in stock and ensuring hygienic passageways can to some extent reduce the transmission of disease (Wells, 1999). However at present, control measures focus on a wide range of preventative and treatment interventions. Best practice needs to incorporate early detection and treatment both to reduce the infection pressure in the environment and ensure effective treatment of individuals (Laven and Logue, 2006; Vink, 2006). The first body of work in this thesis aims to identify the most practical method of identifying individual cases of the disease to carry out regular on farm detection and treatment (Chapters two, three and four).

Digital dermatitis has been described by UK farmers as an intractable lameness problem (Logue et al., 2005). The recommended prevention and control measures, such as underfoot hygiene, within and between herd biosecurity, topical treatment of individual cases and regular routine foot bathing are presently the only management tools available (Logue et al., 2005). Despite these recommendations the disease persists. This suggests prevention approaches are not being implemented vigorously enough at a farm level or are not adequate for disease control.

Herd level intervention is often the strategy of choice by farmers in the UK for both prevention and treatment of DD because of its ease of application (Nuss, 2006, Laven and Logue, 2006). However there is a lack of reliable evidence on the relative efficacy of the variety of foot bath solutions used in an everyday commercial farm setting (Laven, 2003). Few peer-reviewed studies have been published. Laven and Logue (2006) emphasised the need for an assessment of the effectiveness of commonly used treatment interventions. However little is known about the types and frequency of herd treatment interventions farmers use to control the disease, or the effectiveness of these interventions. The later part of this thesis aims to identify the methods used by farmers to control DD at a farm level (Chapter five) and to compare the prevalence and severity of the disease on farms using the two most common treatment approaches in a one year longitudinal study (Chapter six).

1.4.1 Individual cow treatment

Individual topical treatment, with oxytetracycline is currently considered best practice intervention for the treatment of DD. Oxytetracycline is licensed specifically for the treatment of DD in the UK. Other topical antibiotic sprays used include lincomycin and valnemulin (Laven and Hunt, 2001). A micro dilution method was recently developed to determine the in vitro susceptibilities of nineteen UK DD treponemes to eight antimicrobials (Carter et al., 2009). Treponemes showed the highest susceptibility to penicillin and erythromycin (Carter et al., 2009).

Response to topical treatment will depend on a number of factors: the stage at which the lesion is treated, whether the area is pre cleaned to ensure maximum contact with the antibiotics, whether treatment is repeated and the aftercare and environmental hygiene (Vink, 2006). Bandages can also be applied to prolong the contact and therefore efficacy of the antibiotic with the lesion(s), as well as avoiding contact with slurry. Individual treatment can alleviate individual cases, reducing infection within the herd (Laven and Logue, 2006).

Concerns raised by both organic and conventional farming surrounding antibiotic resistance, environmental contamination, milk withdrawal and increasing cost of treatment have fuelled research into non antibiotic alternatives. Although the efficacy of such products has not been scientifically appraised, a number of non-antibiotic bactericidal products are in use, such as acidified sodium chlorite solution and copper sulphate. In addition, antiseptics are also in use, such as acidified copper salts and organic acids. A survey into management decisions farmers take to prevent, detect and treat DD to determine the frequency at which farmers use non antibiotic alternatives and their attitude towards their efficacy is reported in chapter five.

There is some disagreement between researchers, veterinary surgeons and farmers over the use and efficacy of systemic antibiotics for the treatment of DD (Laven and Logue, 2006). Several studies advocate their use (Read and Walker, 1998; Rutter et al., 2001). Rutter et al., 2001 treated fifty cows for three consecutive days with cefquinome (Cephaguard, Intervet Animal Health) which is licensed for the treatment of DD in the UK and found a cure rate of eighty two percent compared to no cure rate in the untreated cows. However other researchers do not advocate the use of systemic antibiotics for the treatment of the disease (Blowey and Sharp, 1988; Britt et al., 1996).

The evidence remains equivocal and the high cost and milk withdrawal associated with systemic antibiotics may mean that farmers are less motivated to use them as a routine treatment intervention. Farmers' attitude towards the use of systemic antibiotics and their effectiveness were investigated as part of the farmer survey (summarised in chapter five).

1.4.2 Herd level treatment

Used for both prevention and treatment purposes, foot bathing has been widely implemented in the UK (Laven and Logue, 2006). There are several perceived advantages to this practice. Treating at a herd level negates the need to identify individual cases, which is seen as time and labour intensive (Laven and Logue, 2006), particularly in larger herds or during an episode of high prevalence. Foot bathing has been advocated as a preventative measure (Laven and Logue, 2006); reducing the infection pressure, disinfecting infected cows that have yet to develop lesions as well as treating lesions early, limiting disease progression and the development of chronic cases.

However, achieving an effective footbathing intervention is not always easy in practice (Nuss, 2006). Footbaths are widely used but the design and frequency of use varies from farm to farm which can affect their success (Cook et al., 2011). Cows can defecate in the footbath, inactivating the solution (Laven and Logue, 2006). Where cows' feet are encrusted with slurry, the lesions' contact with the solution will be limited. A pre wash water footbath designed to wash feet before running cows through the intervention footbath should be used or the hosing of feet down in the parlour (Archer et al., 2010). The perceived cost associated with the solution may encourage farmers to use a reduced concentration resulting in a less effective solution. Furthermore, it has been suggested that the time and labour associated with setting up and running cows through a footbath is equal to establishing hygienic foot conditions on a farm (Nuss, 2006).

Formalin, copper sulphate, peracetic acids, zinc sulphate and sodium hypochlorite are popular non-antibiotic alternative footbathing solutions, despite a lack of scientific evidence for their effect. Several researchers have reported the efficacy of formalin on reducing the prevalence of DD lesions (Blowey, 2000). However the use of this solution is more difficult to advocate from a welfare perspective due to the pain caused when it makes contact with a digital dermatitis lesions. The evidence for the efficacy of copper sulphate is equivocal. Several researchers support its efficacy at a 5% concentration (Speijers et al., 2010; Teixeira et al., 2010), where as previous research has suggests it is not effective in all cases (Rodriguez –Lainz et al., 1996).

Footbathing is carried out in severe outbreaks in preference to individual topical treatment despite evidence that topical treatment is more effective (Laven and Logue, 2006). The overall prevalence of the disease can be under-perceived if treatment becomes disengaged from individual cases (Vink, 2006). Several researchers have found that individual lesions respond better to topical treatment compared to footbathing (Nowrouzian and Zareii, 1998, Laven and Logue, 2006). Nowrouzian and Zareii (1998) found that lincomycin applied as a topical spray was significantly more effective at improving lameness score than the same concentration applied using a footbath. The practices and efficacy of DD intervention on farm is the subject of chapters 5 and 6.

1.5 Scope of thesis

The research presented in this thesis was conducted at the University of Bristol as part of a Tubney Charitable Trust funded ***The Healthy Feet Project:*** *Working together to reduce cattle lameness*. The overall objective of this research was to investigate novel and existing methods of detecting DD, in order to validate an outcome measure for assessing the effectiveness of treatment strategies employed by UK dairy farmers. The project took a multidisciplinary approach, drawing from veterinary, behavioural, welfare and social science as a means of advancing our knowledge of managing the disease.

In order to assess the effectiveness of farmer led treatment strategies for DD, a reliable method of disease detection is essential. Scoring the prevalence and severity of the disease using novel and existing methods was investigated in order to establish the most practical, reliable and feasible detection strategy for routine assessment across a whole herd. The second chapter focuses on methods of visual detection, comparing several ways of viewing and describing DD. Chapter three explores the potential of infrared thermography for diagnosing DD specifically, and detecting generic foot disorders. Locomotion scoring and behavioural observations were assessed for detecting foot disorders in the fourth chapter.

A telephone survey was carried out to illustrate the ways in which farmers make management decisions to detect, treat and prevent the disease, summarised in chapter five. Using the detection method validated in chapter two as an outcome measure for the prevalence and severity of DD, a longitudinal farm based study was carried out to investigate and compare the effectiveness of two common treatment strategies used by UK dairy farmers. Chapter six explores the impact of individual versus herd level intervention on the prevalence and severity of the disease over a year study period, factoring initial DD prevalence, herd size and time of year into consideration. Chapter seven reviews and summarises the main research findings and sets them in the context of future research priority.

Chapter 2

Assessing the reliability of three methods for viewing and categorising digital dermatitis

2.1 Introduction

Improved disease detection is essential to minimise constraints on animal welfare and productivity in farm animal production (Scott et al., 2003). When developing a method of disease detection, it is necessary to assess its reliability. The reliability of a measure is quantified by the errors inherent in the scores generated by the method and is based on the assumption that there is a true underlying score for each individual and a measurement error associated with that score (Scott et al., 2003).

A reliable method of screening cows for the presence/absence, stage and severity of DD required assessing the effectiveness of management and treatment strategies. Such a tool would be equally important in both a research and a herd health management context. It could be used to detect individual cases for treatment, as well as to monitor the effectiveness of herd management strategies over time.

Traditionally, gold standard detection of DD is carried out by visual inspection of the lifted foot with the cow restrained in a crush (Blowey and Sharp. 1988; Blowey, 1992; Murray et al. 1996; Murray et al. 2002; Vink, 2006). However, this method is time, labour and cost intensive. It is particularly impractical for assessing a whole milking herd, or a number of herds on a regular basis. Many farmers have adopted herd level DD management strategies (i.e. footbathing) that negate the need for individual cow identification (Vink, 2006). However, in order to monitor disease levels on farm and/or the effectiveness of treatment a reliable, non-invasive, economically viable method of individual cow detection is required.

As a result, research has focussed on methods of DD detection that do not require the cow's foot to be lifted. The approach most widely adopted in practice is to squat down behind the cow and illuminate the plantar area of the foot (Vink, 2006). However, early lesions are often small, and the cows' feet are covered in dirt and manure, which may lead to an under recording of disease prevalence (Vink, 2006). The angle of the foot in relation to the floor can also make it difficult to inspect the typical lesion site between the heel bulbs. Milking parlours equipped with pits that allow an eye level view of the cows' feet lend themselves to routine foot inspection.

Rodriguez-Lainz et al., (1998) observed individual cows in a milking parlour for approximately two minutes each and found an apparent DD prevalence of 20.5% (24/117) compared with an actual prevalence of 27% (32/117) determined at a later date by examining cows in the crush. The milking parlour sensitivity was 0.72 (95% confidence interval: 0.53-

0.86), and specificity was 0.99 (95% confidence interval: 0.93-0.99). However, true lesion status could have changed during the time lapse of up to a month between the milking parlour and crush inspections. Recently, Thomsen et al. (2008) investigated a more rapid screening method taking approximately 15 seconds per cow observation in the parlour. This study used three test herds and found a sensitivity of 0.65 (95% confidence interval: 0.59 to 0.72) and specificity of 0.84 (95% confidence interval: 0.81 to 0.87) in the parlour compared to a gold standard inspection in the crush. These studies can only be compared with caution since the time taken to inspect each cow differed. However they suggest that by increasing the time per cow observation, the reliability of a screening method in the parlour can increase.

Roger Blowey modified a Borescope to aid visual inspection of the lesion site in the standing foot by attaching a metal plate to the end of the tube which is placed under the cow's foot, providing a reflective surface for the light source to project up into the interdigital space. This modified Borescope (here after Borescope) allowed direct visualisation of the lesion site area at a safe distance from the cow and the light source provided illumination to aid inspection and the optical system provides magnification of the lesion site. Laven (1999) validated the Borescope against a lifted foot inspection in the crush and reported individual lesion specificity of 0.84, and sensitivity of 0.82. The technique was subsequently adopted in several research contexts (Laven & Proven, 2000; Vink, 2006). However, the reliability of a straight forward visual inspection in the milking parlour has not been compared with using the Borescope. In a practical context, the expensive and cumbersome nature of the Borescope prohibits wide scale application on farm as a routine detection aid.

The aim of this study was to identify a practical and efficient means of obtaining the prevalence and severity of DD for a whole milking herd on a regular basis. This study therefore quantifies the errors inherent in scoring DD in the parlour, and with the Borescope, in comparison to a lifted foot inspection as a gold standard. In order to identify a measure to describe the way lesions respond to treatment interventions over time, the reliability of scoring different lesion attributes was observed.

A range of characteristics have been used international to monitor lesion progression over time (Dopfer, 1997; Cruz, 2000; Laven and Proven, 2000; Laven, 2001; Vink, 2006; Holzhauer, 2007). Before a scoring system was developed to describe lesions by stage of infection, studies characterised lesion status by size, depth and colour (Rodriguez-Lainz, 1998; Laven, 1999). These characteristics have the advantage of being simple to measure, however they do not depict the stage of infection. Two scoring systems which describe the various stages of infection were development by Dopfer et al., (1994) and Vink (2006).

Although there is much agreement between these systems, no universal scoring system currently exists. In the UK, Vink (2006) characterised a foot at stage naught where normal digital skin free from a lesion is present. Stage one is characterised by matting of superficial hairs of the affected digital skin with wet eczema which develops into an erosive lesion characterised by loss of stratum corium. Lesions at this stage are prone to bleeding, moist, red in colour and although small (0.5-2cm) can be intensely painful (Vink, 2006). Stage two is characterised by a granulomatous lesion with loss of epidermal and dermal layers and exposed subcutaneous fat. These lesions can reach 7cm in diameter and are demarcated by borders with growth of keratin pins on the surface of the erosions. As keratinisation progresses, lesion size increases (Vink, 2006). Stage three describes a proliferative lesion, characterised by progressive hyperkeratosis. Stage four is characterised by a dark, rubbery, firm scab due to regression after the lesion is treated (Dopfer, 1997). Smooth or scarred skin indicates the completion of infection however hyperkeratosis can indicate that regression is superficial (Dopfer, 1997).

In view of the variety of detection methods and lesion attributes which have been used previously, this study aimed to evaluate and compare three examination methods (parlour, Borescope and lifted foot) in terms of their sensitivity and specificity of detection, and the agreement between them achieved when assessing the colour, depth, size (Laven, 1999) and stage of lesion (Vink, 2006).

2.2 Method

2.2.1 Farm details

The study was carried out on three farms to ensure a wider spread of lesion stages which may be affected by the prevalence and disease dynamics of DD on each farm. All farms were served by the University of Bristol Farm Animal Practice in Somerset milking Holstein Fresian crosses with an average 305 day yield of 8,400kg, ranging from 7,000 – 9,500kg. The average herd size was 153, ranging from 120 to 200 cows. Two farms had all year round calving and one carved from January to August. The selection criteria were for herds endemically infected with DD and where the herdsman was willing for a researcher to examine cows on two consecutive milkings (afternoon and the following morning) each week over a period of four months. All farms had herringbone parlours to enable examination from the pit and a farm crush for the lifted foot examination.

2.2.2 Cow selection

On each visit cows were first inspected in the milking parlour by hosing off their feet during afternoon milking. At this stage four individuals were selected and lesion scored in the parlour (as described in 2.2.2). The herdsman picked the same cows out the next morning for examination using the farm crush. Data were collected between February and May, 2008.
At each afternoon milking visit, up to four cows were selected to fit into one of two groups: 1) two cows with no lesions on the hind feet (control), and 2) two cows with a DD lesion of varying size (0.1-6cm in diameter at the widest point) on the hind feet. Cows were selected for the control group if, during the parlour inspection, they had no visible lesions at the heel, coronary band or interdigital space. Cows were selected for the DD group if they had no other skin disease visible in the standing foot. The same cow was only selected once over the course of the study. A sampling strategy was employed were one cow per row was selected for inspection. Prior to cluster attachment, starting at the end of the row each cow's foot was cleaned off with a high pressure hose until a cow eligible for one of the two groups was identified. The nozzle was angled downwards across the hoof hitting the heel at approximately a 45° angle to ensure minimal splash up and reducing spread of slurry.

2.2.3 Scoring in the milking parlour (parlour screening)

Following selection, the typical lesion site areas on the cows' hind feet (the pastern, accessory digits, coronary band and interdigital space) were then visually examined carefully using a head torch to supply additional lighting. The presence and absence of DD on each hind foot was recorded along with the size, stage, colour and depth of lesions (see 2.2.6 for lesion descriptors). The freeze brand numbers for the selected cows were given to the herdsman so they could be drawn out during the following milking to inspect in the farm crush.

2.2.4 Borescope inspection

The next morning, each cow in turn was moved into the farm crush. The hind feet up to the dew claws were cleaned with a high pressure hose and then dried off with paper towelling. Each hind foot was then inspected using the Borescope. The presence and absence of DD was recorded, followed by the size, stage, colour and depth of lesion (see 2.2.6 for lesion descriptors).

2.2.5 Inspection in the crush

Each hind foot was then lifted using a ratchet system in the crush and scored for the presence and absence of DD along with the size, stage, colour and depth of lesions (see 2.2.6 for lesion descriptors) to obtain the gold standard data. All active DD lesions, regardless of stage, were then sprayed with oxytetracycline spray, which was left to dry and then sprayed again. Each hind foot was trimmed using the functional foot trimming method, and the presence of sole lesions (sole haemorrhage, sole ulcer, white line disease, interdigital growths) were recorded. Hoof trimming knives were cleaned with antibacterial wipes between foot inspections and washed with Fam30 (Evans Livestock Production) at the end of each farm visit, along with all protective clothing and boots.

2.2.6 Lesion descriptors

Characterisation of lesion attributes included the stage scoring system described by Vink (2006, Figure 2.1), the depth (Figure 2.2) and colour description (cream, yellow, grey, brown, black, pink, or red) based on Laven (1999) and an objective measurement of size measured in millimetres with a tape measure. When different stages and colours of lesion were present within a single lesion, the description covering the largest surface area was recorded.

2.2.7 Statistical analysis

Raw data was entered into an Excel spreadsheet (Microsoft Office version 97-2003) then transferred into SPSS (Version 16.0) and Gen Stat (Version 10.1) for analysis. Data was analysed at a foot level. Percentage agreement, sensitivity and specificity for the presence/absence of DD and lesion characteristics using the parlour screening technique and Borescope were calculated in Excel using the lifted foot method as gold standard. Sensitivity was assessed as the proportion of true positives identified in the parlour and by the Borescope as compared to those identified when the foot was lifted. Specificity was assessed as the proportion of true negatives identified in the parlour and by the Borescope as compared to those identified when the foot was lifted. Categorical (stage, depth and colour) data were transformed to binary data to assess the agreement between each paired combination of methods of detection for each parameter using Cohen's kappa coefficient. For example, each stage of lesion was compared against all other combined stages (where erosive = 1, granulomatous, proliferative and regressing = 0; where granulomatous = 1, erosive, proliferative and regressing = 0; where proliferative = 1, erosive, granulomatous and regressing = 0; and where regressing = 1, erosive, granulomatous and proliferative = 0). Landis and Koch (1977) defined Kappa as: poor agreement = >0.00, slight agreement = 0.00-0.20, fair agreement = 0.21-0.40, moderate agreement = 0.41-0.60, substantial agreement = 0.61-0.80, almost perfect agreement = 0.81-1.00. Kendall's coefficient of concordance was used to assess the agreement for the size of lesions (ordinal data) using Gen Stat (Version 10.1). The level of significance was set at $p < 0.05$.

2.3 Results

2.3.1 Descriptive statistics

A total of 80 cows were examined during the course of the study, of which 37 (46%) cows had no DD (group one: controls) and 43 (54%) cows presented with DD (group 2: DD lesion size 0.1-6cm). In total, 39 small (0.1 to 1cm) and 47 large (1.1 to 6cm) lesions were observed (86 in total). Tables 2.1, 2.2 and 2.3 summarise the frequency and percentage of lesions scored as presence or absence and by stage, colour, depth and size of lesion using each of the three observational methods. Table 2.1 illustrates that with the exception of one lesion, the parlour method correctly identified all lesions as present and absent when compared with the lifted foot. Table 2.1 shows that using the parlour and Borescope inspections resulted in an underestimate of the number of erosive lesions but an overestimate of the number of granulomatous lesions when compared with the examination in the crush. The stage of lesion was closely linked to lesion colour and consequently Table 2.2 shows that pink/red (erosive) lesions were underestimated and cream/yellow (granulomatous) lesions were overestimated during the parlour and Borescope inspections, verifying the data in Table 2.1. Table 1 also suggests that there was more agreement between viewing methods when categorising proliferative and regressing lesions, more advanced stages of disease progression. Consequently there is more agreement between the brown/black colour descriptor and the protruding depth descriptor in Table 2. Shallow lesions were overestimated using the parlour and the Borescope; whereas deep lesions were underestimated. Size measuring the diameter at the widest part of the lesion in the parlour and at the Borescope inspection did not meet perfect agreement with the measurement taken in the crush, where parlour and Borescope inspections lead to both an over and under recording of actual size for lesions less than 4cm.

2.3.2 Inferential statistics

Tables 2.4-2.7 summarise the percentage agreement, Kappa coefficient, sensitivity and specificity between the parlour, Borescope and examination in the crush for each binary parameter at a foot level. All Kappa values are significant at the $p < 0.001$ level. As the agreement between the parlour, Borescope and examination in the crush for the presence and absence of DD was near perfect, all feet with a DD lesion regardless of lesion size were analysed together.

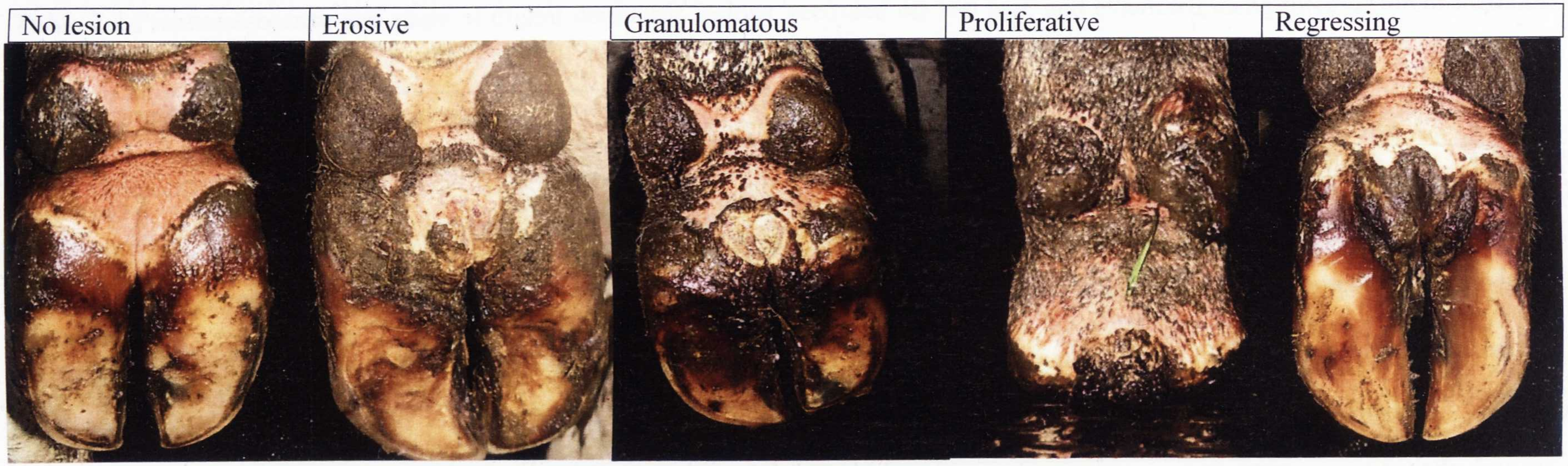


Figure 2.1 Stage scoring system as described by Vink (2006)

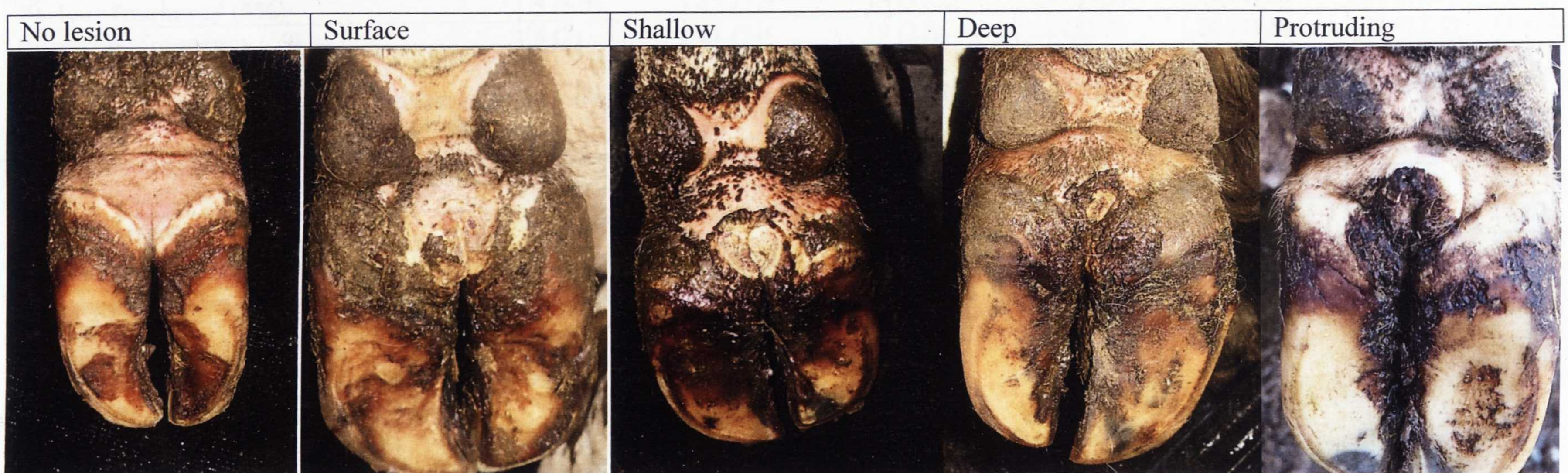


Figure 2.2 Depth scoring system as described by Laven (1999)

Table 2.1 Presence/absence and stage of digital dermatitis lesions, recorded on 160 feet, and examined using three different methods. Number (percentage) of lesions

Detection method	**DD Lesion**		**Stage of lesion**			
	Present	Absent	Erosive	Granulomatous	Proliferative	Regressing
Crush (%)	**86 (53.8)**	**74 (46.2)**	**18 (20.9)**	**34 (39.6)**	**16 (18.6)**	**18 (20.9)**
Parlour (%)	**87 (54.4)**	**73 (45.6)**	**11 (12.6)**	**45 (51.8)**	**16 (18.4)**	**15 (17.2)**
Borescope (%)	**86 (53.8)**	**74 (46.2)**	**15 (17.4)**	**41 (47.8)**	**15 (17.4)**	**15 (17.4)**

Table 2.2 Colour and depth of digital dermatitis lesions, recorded on 160 feet, and examined using three different methods. Number (percentage) of lesions

Detection method	**Colour**			**Depth of lesion**			
	Pink/red	Cream/ yellow	Brown/ black	Surface	Shallow	Deep	Protruding
Crush frequency (%)	**14 (16.3)**	**53 (61.6)**	**19 (22.1)**	**30 (34.9)**	**32 (37.2)**	**14 (16.3)**	**10 (11.6)**
Parlour frequency (5%)	**5 (5.8)**	**67 (77)**	**15 (17.2)**	**29 (33.3)**	**36 (41.5)**	**11 (12.6)**	**11 (12.6)**
Borescope frequency (%)	**6 (7)**	**61 (71)**	**19 (22)**	**28 (32.5)**	**36 (41.9)**	**11 (12.8)**	**11 (12.8)**

Table 2.3 Size of digital dermatitis lesions, recorded on 160 feet, and examined using three different methods. Number (percentage) of lesions

Detection method	**Size of lesion (diameter at widest point measured in millimetres)**					
	0.1 to 1	1.1 to 2	2.1 to 3	3.1 to 4	4.1 to 5	5.1 to 6
Crush frequency (%)	**39 (45.4)**	**23 (26.7)**	**6 (7)**	**13 (15)**	**4 (4.7)**	**1 (1.2)**
Parlour frequency (5%)	**42 (48.3)**	**20 (23)**	**9 (10.3)**	**11 (12.6)**	**4 (4.6)**	**1 (1.2)**
Borescope frequency (%)	**38 (44.2)**	**22 (25.6)**	**11 (12.8)**	**10 (11.5)**	**4 (4.7)**	**1 (1.2)**

Table 2.4 The percentage agreement, kappa values, sensitivity and specificity for the presence and absence of digital dermatitis and the colour of lesions

Detection method	**Presence/absence of lesion**				**Colour of lesion**											
					Pink/red				Cream/yellow				Brown/black			
	Percentage agreement	Kappa	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity
Parlour and crush	**99**	**0.99**	**1.00**	**0.99**	**0.38**	**90**	**0.36**	**0.99**	**0.68**	**84**	**0.95**	**0.68**	**0.77**	**95**	**0.67**	**0.98**
Borescope and crush	**100**	**1.00**	**1.00**	**1.00**	**0.59**	**96**	**0.36**	**0.93**	**0.70**	**86**	**0.87**	**0.77**	**0.54**	**89**	**0.78**	**0.90**
Parlour and Borescope	**99**	**0.99**			**0.46**	**91**			**0.70**	**85**			**0.73**	**93**		

Table 2.5 The percentage agreement, kappa values, sensitivity and specificity for the stage of lesion

Detection method	**Stage of lesion**															
	Erosive				Granulomatous				Proliferative				Regressed			
	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity
Parlour and crush	**0.64**	**91**	**0.55**	**0.99**	**0.55**	**79**	**0.93**	**0.75**	**0.81**	**95**	**0.67**	**0.99**	**0.71**	**92**	**0.67**	**0.98**
Borescope and crush	**0.65**	**93**	**0.65**	**0.94**	**0.70**	**85**	**0.90**	**0.77**	**0.70**	**92**	**0.71**	**0.89**	**0.83**	**96**	**0.52**	**0.97**
Parlour and Borescope	**0.78**	**94**			**0.67**	**85**			**0.72**	**92**			**0.66**	**92**		

Table 2.6 The percentage agreement, kappa values, sensitivity and specificity for the depth of lesions

Detection method	**Depth of lesion**															
	Surface				Shallow				Deep				Protruding			
	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity
Parlour and crush	**0.57**	**83**	**0.66**	**0.89**	**0.52**	**78**	**0.73**	**0.89**	**0.79**	**92**	**0.57**	**0.96**	**0.63**	**97**	**0.86**	**0.98**
Borescope and crush	**0.65**	**86**	**0.66**	**0.90**	**0.63**	**83**	**0.84**	**0.81**	**0.85**	**96**	**0.71**	**0.92**	**0.74**	**98**	**0.71**	**0.95**
Parlour + Borescope	**0.68**	**87**			**0.72**	**87**			**0.76**	**95**			**0.77**	**97**		

Table 2.7 The percentage agreement, kappa values, sensitivity and specificity for the means of the values for each lesion parameter

	Size		**Colour**				**Stage**				**Depth**			
Detection method	Percentage agreement	Kendall coefficient	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity	Kappa	Percentage agreement	Sensitivity	Specificity
Parlour and crush	**85**	**0.90**	**0.61**	**90**	**0.66**	**0.88**	**0.68**	**89**	**0.71**	**0.93**	**0.63**	**88**	**0.71**	**0.93**
Borescope and crush	**89**	**0.90**	**0.63**	**90**	**0.67**	**0.87**	**0.71**	**91**	**0.70**	**0.89**	**0.73**	**92**	**0.73**	**0.90**
Parlour and Borescope	**89**	**0.90**	**0.61**	**90**			**0.72**	**92**			**0.72**	**91**		

2.4 Discussion

The aim of this study was to find a practical, time efficient and reliable method of regularly screening a herd of cows for DD lesions. This study compared the reliability of detecting and categorising DD lesions in the standing foot in the milking parlour and, with the aid of the Borescope, against that of the lifted foot inspection. With the exception of one lesion, the parlour screening (percentage agreement 99%, sensitivity 1.00 and specificity 0.99) was as reliable as the Borescope (percentage agreement 100%, sensitivity 1.00 and specificity 0.99) for determining the presence and absence of DD lesions when compared with the crush. The Borescope had no added value for screening cows. Screening cows in the parlour is a reliable and practical means of detecting the presence and absence of DD regardless of the stage of lesion development.

In order to monitor the effect of treatment over time, it is necessary to identify a means of describing lesion characteristics in a meaningful way. The Kappa coefficients calculated between parlour, Borescope and lifted foot inspection, for the stage, colour and depth of lesions all met the criterion for substantial agreement. However, the stage scoring system inherently incorporates colour (as evidenced by the relationships seen between the results of Tables 1 and 2) and depth characteristics, as well as describing the progression of lesions over time.

The agreement between the lifted foot and standing foot in the parlour and Borescope inspection for each lesion characteristic did not differ significantly. The purpose of this study was to identify a lesion descriptor that could describe the progression of lesions as an outcome measure for assessing the efficacy of treatment interventions. Lesion stage in the parlour met substantial agreement with the gold standard, whereas size of lesion met near perfect agreement with the lifted foot inspection. The difference in statistical agreement can be partially explained by the methods used to analyse the data. Kendall's coefficient of concordance which was used to analyse the diameter of lesions took into consideration the degree to which two methods do not agree. However Kappa, used to analyse the lesion stage measure, assessed agreement as a yes/no criterion, did not take into account degree of agreement.

The reliability of a measure should be weighed against its usefulness in the context for which it is being used. Scoring lesions by size is an objective measure with no visual interpretation by the observer. However, lesion size alone cannot describe the stage of infection. Lesion size indicates infection severity, although a small lesion is present both at the beginning and the end of infection. Describing lesions by stage lends itself better to investigating lesion progression over time, as well as monitoring the effectiveness of treatment interventions.

Previously Rodriguez-Lainz et al., (1998) found a sensitivity of 0.72 and specificity of 0.99 using a two minutes observation time per cow in the milking parlour. The lower sensitivity reported by Rodriguez-Lainz et al., (1998) compared to this study's findings can be attributed to the time lapse of up to a month between the parlour and crush observations during which it is very likely lesion status would have changed. Thomsen et al., (2008) found an even lower sensitivity of 0.65 and specificity of 0.84 when rapidly screening cows (15 seconds per cow). Taken together with the current findings, this suggests that the reliability of the screening method can increase, if the time taken to inspect each cow increases.

Greater agreement was found between the current experimental methods than previous studies have reported. This variation can be attributed to differences in experimental method, such as the time taken to observe each cow. In the present study the researcher only scored one cow per row, which meant there were minimum time constraints with approximately seven minutes per cow to score a number of lesion characteristics (presence/absence of lesion, size, stage, colour and depth). As a range of lesion characteristics were scored, this study did not try to detect lesions across a whole herd during one milking.

There was a selection bias inherent in the study design as cows were always selected in the milking parlour first and then subsequently re-assessed using the Borescope and the lifted foot examination. Cows were not randomly selected as a balance of infected and non-infected individuals was necessary to allow identification of both true positives and negatives. Cows were selected in the parlour as this was the most practical and time effective method for the amount of recordings that needed to be taken by one observer. If this study was carried out again without limited time and resources, an optimal study design would be to blindly select cows using the gold standard method of examination in the crush and subsequently carry out the Borescope and parlour inspections.

The farm environment may also have an impact on data variation as differences in the conditions (particularly lighting) and equipment for lesion inspection may vary. Additionally, within observer repeatability has an impact but was not measured here. Between observer repeatability could not be investigated within this study as only one researcher carried out all observations.

Further methodological limitations to the present study have to be considered including the fact that it was not possible for the observer to be blinded to the selection history of the cows; therefore the results may be biased by previous examinations. Efforts were made to reduce the observer effect by employing a research technician to record information onto the data collection sheet during the Borescope and crush assessments, thus preventing the researcher from reviewing scores allocated to the cows during the parlour screening. The Borescope and lifted foot inspections were carried out in immediate succession. If the observer bias affected the way lesions were scored, substantially more agreement between the Borescope and the lifted foot inspection than with the parlour screening might be expected. However, this was not found to be the case.

A previous criticism of detecting lesions in the parlour is that small early lesions can be missed (Vink, 2006). However this study suggests that it is possible to detect lesions smaller than 1cm in diameter. This is likely to be due to the rigorous approach of cleaning feet with a high flow rate hose, a powerful light source to illuminate the plantar aspect of the feet, and sufficient time and eye sight to carry out the inspection. The cow sample used here was the size of a small milking herd (80 cows), and no lesions in the interdigital space were present. Therefore the reliability of detecting lesions in the interdigital space in the parlour or using the Borescope could not be assessed. Furthermore, the impact foot hygiene and complex pathologies may have on obscuring lesions was not investigated as part of the present study.

Screening cows for DD in the milking parlour can lead to early treatment, reducing the infection reservoir within a herd which is currently understood to be the lesion itself (Carter et al., 2009). Farmers can screen cows in the parlour to identify cases for treatment, or select cases for later investigation in the crush. Cleaning and inspecting hind feet in the milking parlour can be seen by farmers as an unfavoured task as they perceive that it adds extra time to milking. However, regular cleaning of feet can make individual DD detection easier and early treatment interventions may reduce the likelihood of developing chronic cases (Somers et al., 2003), although the benefits of this procedure as a routine method of disease control have yet to be investigated. Future research should examine the effect a regular foot cleaning intervention has on preventing DD cases, as evidence from risk analysis suggests that poor foot hygiene (Vink, 2006) and prolonged contact with slurry (Rodriguez-Lainz, 1996; Somers et al., 2005a, Bell, 2006) are significant risk factors for DD. The decisions farmers take to manage DD will be explored in some detail in chapter five.

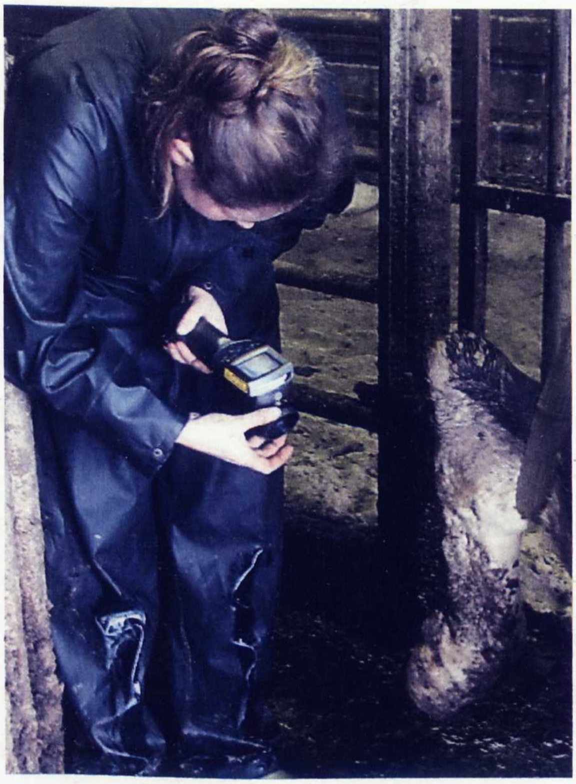
In the case of routine assessments, protocol is largely shaped by the feasibility of regular whole herd lesion monitoring. Detecting lesions in the early stages of infection is clearly important from both welfare and disease management perspectives (Scott et al., 2003). In addition to the methods described here, infrared thermography is a non-invasive technique which has the potential to be used diagnostically to detect early stages of infection. The use of thermography in identifying the presence and absence of DD will be discussed in the next chapter.

2.5 Conclusion

Examination in the parlour following the method described here can be reliably used to identify the presence and absence of DD lesions without having to lift the foot, and to describe lesions by stage to substantial agreement with examination in the crush. This method is feasible for on farm application by a single observer within a half day visit, lending itself to regular cow and herd level lesion monitoring. This method was therefore used in a subsequent study to assess the impact of treatment strategies on the occurrence and recovery of lesions over time (Chapter 6).

Chapter 3

An investigation into the use of thermography (IRT) as a rapid diagnostic tool for digital dermatitis



3.1 Introduction

Early detection of DD is in need of improvement as the first step towards treatment and reduction of infection. In order to inspect the feet of cows for signs of disease, traditional clinical assessment requires lifting each foot using a crush. This is both logistically and economically challenging on a large scale and the reliability of disease detection can vary at an early stage (Schaefer et al., 2004). Locomotion scoring can help identify developing limb pathologies without having to lift the foot but is not always reliable (see Chapter 4) and may not signal early stages of disease. With the number of animals per herd increasing (Defra, 2009), the development of non-invasive tools for detecting early stages of disease can promote early treatment and implementation of preventative measures. For example, the early detection of digital dermatitis could allow rapid treatment of individual cases, reducing the infection pressure within the herd.

Infrared thermography (IRT) is a non-invasive, quantitative assessment of temperature. Infrared thermography gives a pictorial representation of the surface temperature of an object (Purohit and McCoy, 1980; Turner et al., 1986) where the colour gradient reflects differences in emitted heat. Heat is a cardinal sign of inflammation, illustrating an increase in circulation and tissue metabolism (Head and Dyson, 2001; Van Hoogmoed and Snyder, 2002). Monitoring temperature fluctuation can therefore indicate development of inflammation in tissues. Thermal images can be taken at a distance from the subject without undue contact or restraint, avoiding temperature artefacts associated with capture and confinement (Stewart et al., 2005). This technique has been used in both human and veterinary medical research, primarily as a diagnostic tool for the detection of local inflammation due to disease and injury (Schaefer et al., 2004).

Purohit and McCoy (1980) first reported the use of thermography for the detection of lameness and regions of inflammation in horses. Infrared thermography was used to diagnose soft tissue injury and disease in horses, such as laminitis and sole abscess (Turner et al., 1991). In addition to clinical disease diagnosis, IRT has been used to evaluate the effect of topical treatments on skin temperature in horses (Turner et al., 1989),

More recently, IRT has been developed as a tool for early diagnosis of infection in dairy cattle. Schaefer et al. (2004) found that bovine viral diarrhoea (BVD) can be detected through an increase in eye temperature as early as day one of infection, compared to detection on day six using temperature readings at the nose, ear, body or hoof regions. An increase in eye temperature was detectable several days to one week before an objective laboratory test or conventional clinical scoring indicated disease. The authors suggested that IRT could be used to enhance early detection of BVD infection in cattle.

Infrared thermography has also been utilised for the early detection of mastitis in dairy cows (Scott et al., 2000; Berry et al., 2003). Scott et al., (2000) found that inflammation of the udder could be detected using IRT one hour post induction of mastitis, compared to six hours post induction using traditional laboratory methods (somatic cell counts and bovine serum albumin). Researchers have suggested that IRT could be used to automatically screen cows for early temperature changes associated with clinical mastitis in the milking parlour (Colak et al., 2008; Hovinen et al., 2008).

The use of IRT for rapid screening of potentially infected animals with foot-and-mouth disease and after the development of clinical signs was investigated (Rainwater-Lovett et al., 2009). Infected animals had an elevated maximum foot temperature. These temperatures were used to establish an optimum threshold cut off value of 34.4°C for infected animals, which achieved a sensitivity of 61.1% and specificity of 87.7%, which was then used to correctly identifying 63% of pre-clinical cases. Sensitivity and specificity for IRT detection during the clinical stage using this cut off were 79.5% and 87.5%, respectively. At the post clinical stage (second day of clinical disease), sensitivity was 78.1% and specificity was 88.4%. Using the same cut off, IRT detected 50% of infected animals one day prior to the detection of disease in the blood stream (viremia) and two days prior to the presence of foot lesions. The authors conclude that IRT could be used to rapidly screen a large group of potentially infected animals for confirmatory diagnostic testing during foot and mouth outbreaks.

Lameness is one of the most costly and widespread problems facing the dairy industry warranting the development of automated detection methods. Consequently, the potentially of IRT has been investigated to detect inflammation associated with lameness in dairy cows. Research has primarily focussed on the relationship between claw horn lesions and foot temperature. Munsell et al., (2004) found that five days prior to foot trimming, feet that had at least one sole lesion presented a significantly higher temperature at the coronary band compared to feet without sole lesions. However the foot temperature of cows with lesions five days post foot trimming did not differ from cows without lesions. This suggests that IRT can be used to detect a difference in foot temperature associated with claw lesions in cattle. Nikkah et al., (2005) also found an increased temperature at the coronary band associated with sole ulcers and haemorrhages in early lactating cows, and recommended IRT for monitoring changes in hoof health.

To date, research has established that temperature at the coronary band increases with the presence of claw horn lesions. However the reliability of using IRT as a method of differentiating between lesions has not been investigated, which is of relevance as lameness in dairy cows is caused by a number of claw horn and infectious skin diseases (Murray et al., 1996). Previous research has suggested that maximum temperature taken from IRT recordings is a consistent measure of lameness (Whay et al., 2004).

The aim of this study was to examine the potential of IRT as a non invasive tool for rapidly screening dairy cows for the presence of DD. Negating the need to clean or lift the foot would mean that this method could have practical applications. However, previous research has suggested that dirt (Palmer, 1981) ambient temperature and body temperature (Hurnik et al., 1985) influence the reliability of thermography by affecting the surface's ability to radiate absorbed energy (emissivity) and to conduct heat (conductivity). Traditionally, the gold standard for lesion detection is inspection of the lifted foot in the crush (Blowey and Sharp. 1988; Blowey, 1992; Murray et al. 1996; Murray et al. 2002; Vink, 2006). Therefore, in order to establish whether IRT can be used to reliability identify disease without having to clean or lift the foot, thermal images were taken before and after cleaning the feet and compared with a visual inspection of the lifted foot. Ambient temperature and surface body temperature measured at the udder were recorded, in order to investigate the effect these factors have on the cow's skin temperature at the lesion site.

3.2 Method

3.2.1 Farm details and cow selection criteria

The study was carried out on four dairy farms served by the University of Bristol Farm Animal Practice in Somerset (section 2.2.1). Cows were selected according to the method described in section 2.2.2.

3.2.2 Infrared thermography recording at the crush

The data for this study were collected at the same time, and from the same cows as the data reported in Chapter 2. At the inspection visit on the morning following selection (section 2.2.2), each cow was moved into the farm crush where three thermal images (ThermaCAM^{TM} E2, FLIR Systems) were taken of the plantar aspect of each of its hind feet: one of the uncleaned foot in the standing position, one of the standing foot after cleaning as described in 2.2.4, and one of the cleaned foot while lifting as described in 2.2.5. To standardise the area samples and distance at which the image was taken, the camera was held so that a rectangle of fixed size in the middle of the display screen was centred over the pastern and the maximum temperature reading was given for everything viewed within the rectangle as shown in Figure 3.1.

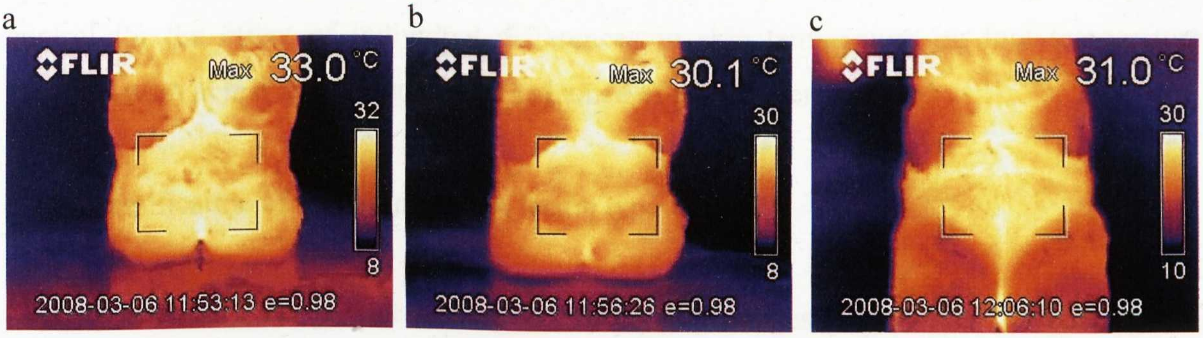


Figure 3.1 Thermal images taken in each condition and presentation (a = dirty, b = cleaned, c = cleaned and lifted). Thermographic images are a pictorial representation of the heat gradients generated by an object. Variations in heat are represented by different colours: the hottest colours are white and the coolest areas are black.

3.2.3 Lesion inspection in the crush

Each foot was scored for the presence and absence of digital dermatitis. In order to gain a gold standard observation of lesion presence, each hind foot was trimmed using the functional foot trimming method and lesions (sole haemorrhage, sole ulcer, white line disease, interdigital growth) were recorded. Hoof trimming knives were cleaned with antibacterial wipes between foot inspections and washed with Fam30 disinfectant at the end of each farm visit, along with all protective clothing and boots. Finally, all active digital dermatitis lesions, regardless of stage were sprayed with oxytetracycline spray, left to dry and then sprayed again.

3.2.4 Control of artefacts

Previous research has suggested several factors can influence the reliability of IRT. The following control measures were taken in the study described here. The camera was set so that a fixed size rectangle shown in the middle of the screen was centred over the plantar aspect of the foot where the top of the rectangle lined up with the bottom of the accessory digits and the bottom of the rectangle fell over the top of the heel bulbs. Where possible, cows were scanned while in a shaded area to avoid the effect of sunlight shining directly on the skin. Recordings were taken at the same time of day to control for circadian rhythm effects (Kendall and Webster 2009). The ambient temperature was also recorded using a handheld thermometer after five minutes of being placed adjacent to the farm crush to account for varying environmental temperature. Thermal temperatures were taken from the udder to obtain a reference skin temperature from an area without hair covering. This was to control for the effect of individual differences in skin temperature on foot temperature. Animals were at rest and not under the influence of recent exercise.

3.2.5 Classification of feet according to lesion type

Maximum thermal temperatures were obtained from images of 164 feet (82 cows) under three foot conditions (dirty, clean and lifted feet). Thermographic data for four cows was not obtained due to equipment failure on farm. The data were analysed at a foot level. Each cow's foot was allocated to a group according to the lesions present. Group one = feet with no lesions (controls, N = 41), group two = feet with lesions other than DD () (N = 29), group three = feet with DD lesions only (N = 52), and group four = feet with both DD lesions and other lesions (N = 42).

3.2.6 Data analysis

Statistical analysis was carried out using PASW Statistics 17. Descriptive statistics were calculated for maximum foot temperatures by lesion group (mean, standard deviation). The Kolmogorov-Smirnoff test was used to test variables for normality, supported by skewness and kurtosis, histograms, normal Q-Q Plots and Detrended Normal Q-Q Plots. Correlation coefficients and coefficients of determination were used to investigate the relationship between ambient temperature, udder temperature and maximum foot temperature. Ambient temperature was found to be negatively skewed towards the lower values (mean 14.57°C ± 0.418, sd 4.88, median 12.4°C, range 7-31°C) and core body temperature was positively skewed towards the higher values (mean 34.83°C ± 0.116, sd 1.34, median 35°C, range 31-37°C). Therefore, Spearman's Rank Order Correlation (rho) was used to calculate the strength of relationship between ambient, udder and foot temperature. Regression was used to determine the variance in foot temperature explained by ambient and udder temperature.

Overall temperatures across all feet and temperatures by lesion group followed a normal distribution. A one way repeated measures ANOVA was used to test for a difference in temperature between foot conditions and foot presentations (dirty, clean and clean lifted). A one way between groups ANOVA was used to test for a difference in foot temperature between lesion groups. Different maximum temperature thresholds were tested to find the one which gave the best agreement with the gold standard of visual detection of lesions. Sensitivity, specificity and Cohen's Kappa coefficient were used to determine whether the agreement between feet above the temperature threshold and the presence of any lesion was reliable.

3.3 Results

3.3.1 The relationship between udder, ambient and foot temperature

Figure 3.2 illustrates the small but significant positive correlation between ambient temperature and temperature of dirty feet (Spearman's rho 0.307, $p < 0.01$). Although there was a small correlation between ambient temperature and dirty foot temperature, the coefficient of determination illustrates that ambient temperature can only account for 8.2% of the variation in temperature of dirty feet (regression equation, Figure 3.2). There was also a small, significant positive relationship between ambient temperature and foot temperature after the feet had been cleaned (Spearman's rho 0.271, $p < 0.01$), but ambient temperature could only account for 9.3% of the variation in foot temperature (regression equation, Figure 3.3). Similarly, ambient temperature had a small relationship with foot temperature after the foot had been cleaned and lifted (Spearman's rho 0.211, $p < 0.05$), but this only accounted for 5.7% of the variation explained (regression equation, Figure 3.4). As less than 10% of the variance explained in maximum foot temperature is accounted for by ambient temperature, values were not adjusted (Field, 2009).

There were no significant correlations between skin temperature measured at the udder and maximum foot temperature (see Figures 3.5-3.7). Udder temperature could only account for 3% of the variation in temperature of dirty feet (regression equation, Figure 3.5), 1.6% of the variability in temperature of clean feet (regression equation, Figure 3.6) and 1.2% of the variability in temperature of clean lifted feet (regression equation, Figure 3.7).

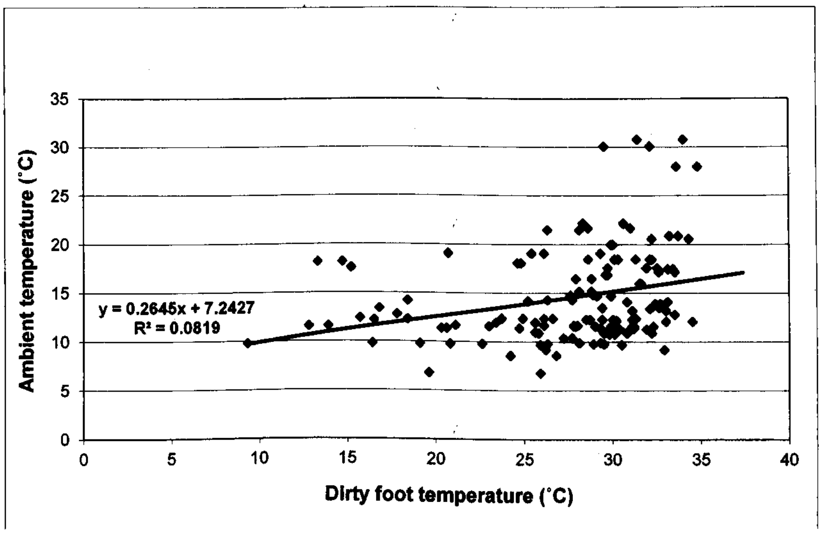


Figure 3.2 Scatter plot illustrating a small positive correlation between ambient temperature and maximum temperatures at the pastern before feet were cleaned (dirty).

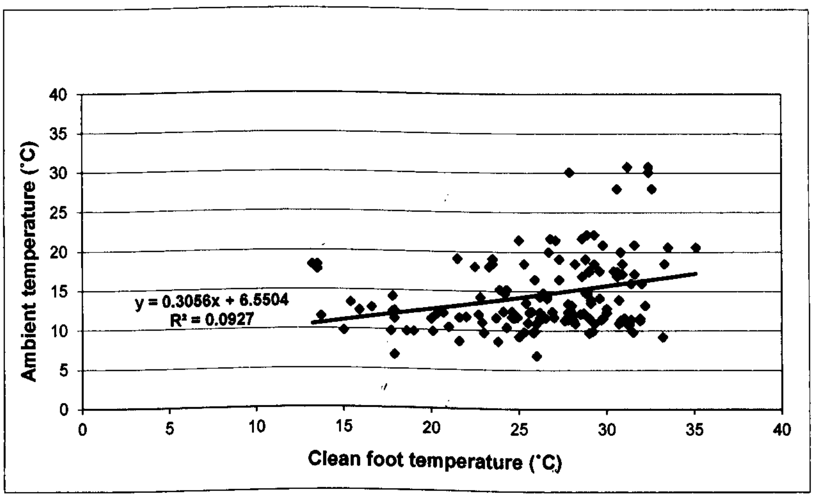


Figure 3.3 Scatter plot illustrating a small positive correlation between ambient temperature and maximum temperatures at the pastern after feet were cleaned (clean).

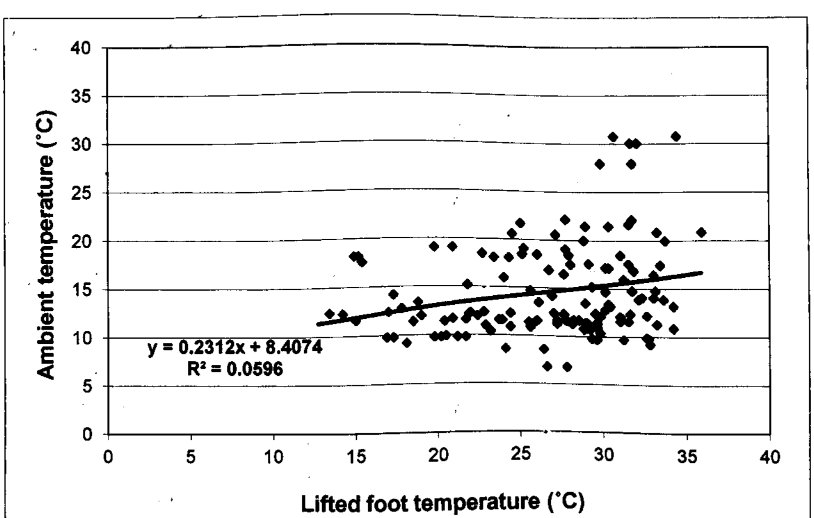


Figure 3.4 Scatter plot illustrating a small positive correlation between ambient temperature and maximum temperatures at the pastern after feet were cleaned and lifted (lifted).

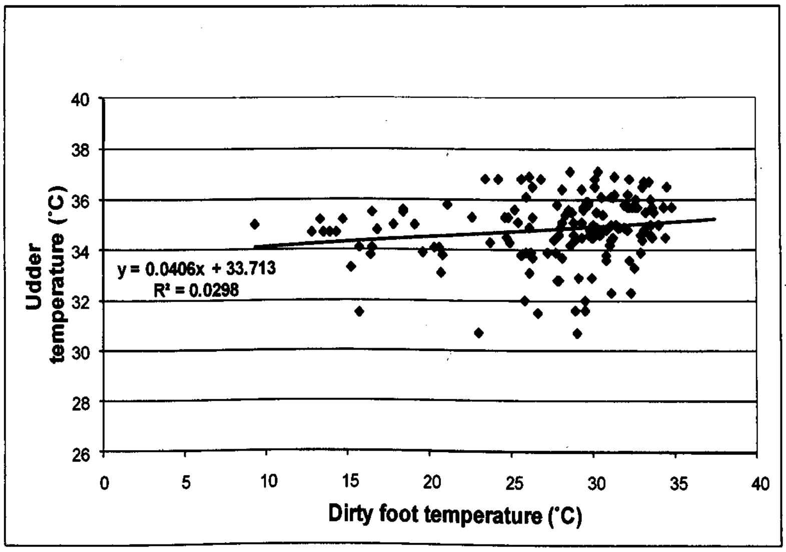


Figure 3.5 Scatter plot illustrating the relationship between udder temperature and maximum foot temperatures at the pastern before feet were cleaned (dirty).

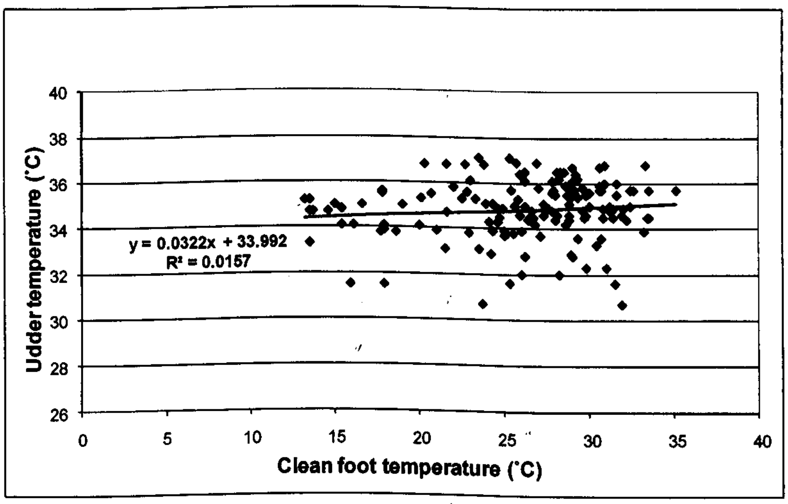


Figure 3.6 Scatter plot illustrating the relationship between udder temperature and maximum foot temperatures at the pastern after feet were cleaned (clean).

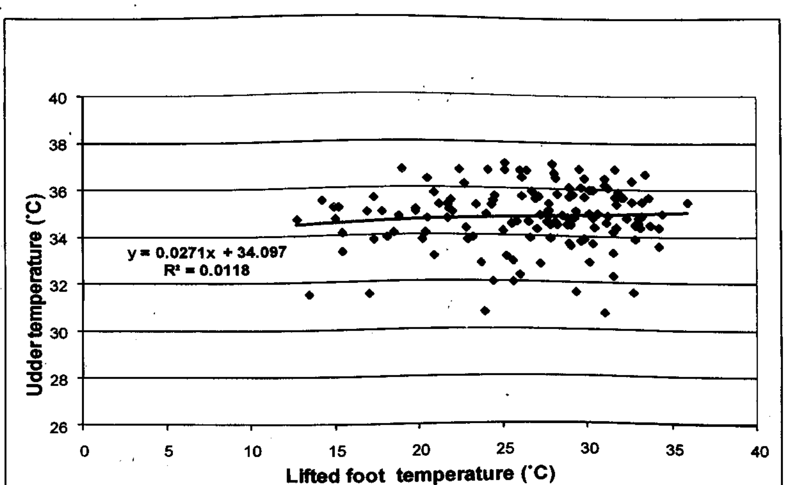


Figure 3.7 Scatter plot illustrating the relationship between udder temperature and maximum foot temperature at the pastern after feet were cleaned and lifted (lifted).

3.3.2 The effect of foot condition on foot temperature at the pastern

Figure 3.8 illustrates the mean maximum temperature obtained at the pastern while feet were dirty (mean 27.6°C, s.d. 5.61), clean (mean 26.2°C, s.d 5.16) and lifted (mean 26.7°C, s.d. 5.29). A one-way repeated measures ANOVA was used to compare maximum temperature under the three conditions. There was a significant effect of condition on foot temperature ($\Lambda = 0.734$, $F(2,162) = 29.3$, $p < 0.001$, $\omega^2 = 0.27$). Despite reaching statistical significance, the actual difference in mean scores between conditions was small. The maximum difference in mean scores was between dirty and clean feet at 1.4 degrees. Post-hoc tests identified that dirty feet had significantly higher temperature than clean feet ($p < 0.001$) and lifted feet ($p < 0.01$). However temperature was not significantly different between clean and lifted feet ($p > 0.05$).

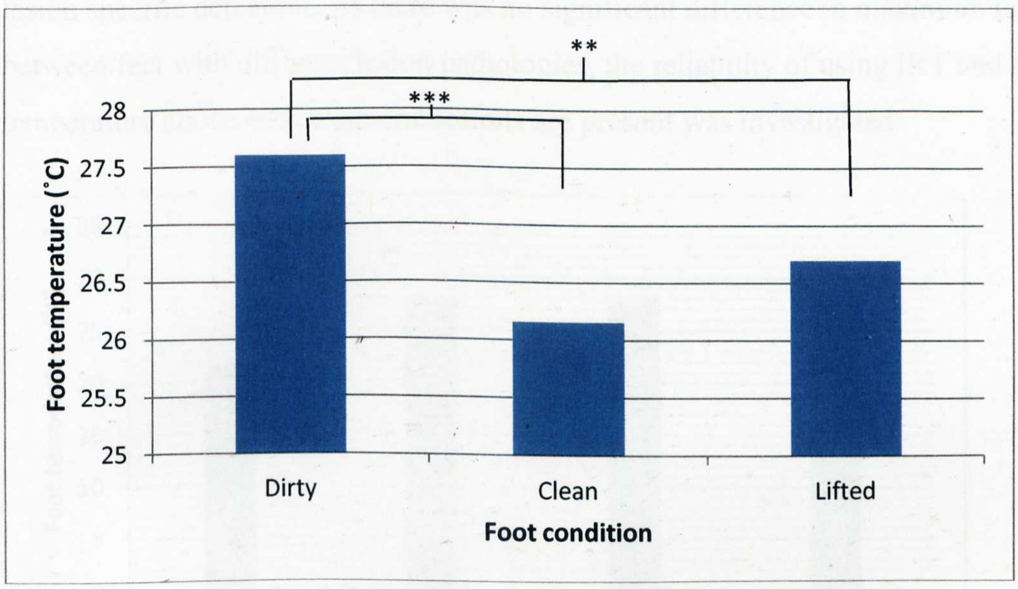


Figure 3.8 Bar chart illustrating the mean of maximum temperatures at the pastern of dirty, clean and lifted feet (** = $p < 0.01$, *** = $p < 0.001$).

3.3.3 The effect of lesion type on mean maximum foot temperature at the pastern

Figure 3.9 demonstrates the mean maximum foot temperature by lesion group (as classified in section 3.2.7). Figure 3.9 illustrates that feet with no lesions have a lower maximum foot temperature at the pastern than feet with any type or combination of foot lesion. Figure 3.10 illustrates the mean maximum foot temperature by lesion group under each foot condition (dirty, clean and lifted). Figure 3.10 illustrates that there is more variation in temperature between feet with and without foot lesions compared to feet across conditions. Descriptive statistics are shown in Table 3.1. The standard deviation in temperature is greater in feet classified with no lesions than feet classified with any type of foot lesion. A one-way between-groups analysis of variance was conducted to explore the impact of lesion group on foot temperature under each condition (dirty, clean and lifted). In Table 3.1, within a row, values with different superscripts indicate significant differences between lesion groups. There was a significant difference in foot temperature between lesion groups: dirty (F (3,160) = 25.4, $p < 0.001$, $\omega^2 = 0.32$), clean (F (3,163) = 17.17, $p < 0.001$, $\omega^2 = 0.24$), and lifted (F (3,160) = 15.57, $p < 0.001$, $\omega^2 = 0.23$). Post-hoc comparisons using the Tukey HSD test indicated that feet with DD (group 3), other lesions (group 2) and both DD and other lesions (group 4) had significantly higher foot temperatures compared to feet with no lesions (group 1) ($p > 0.001$). However, the temperature between feet with DD lesions (group 3), other lesions (group 2) and DD and other lesions (group 4) did not differ significantly, regardless of whether the feet were dirty, clean or lifted. This suggests IRT is not sensitive enough for lesion specific detection. As there was no significant difference in maximum temperature between feet with different lesion pathologies, the reliability of using IRT and a threshold temperature above which generic lesions are present was investigated.

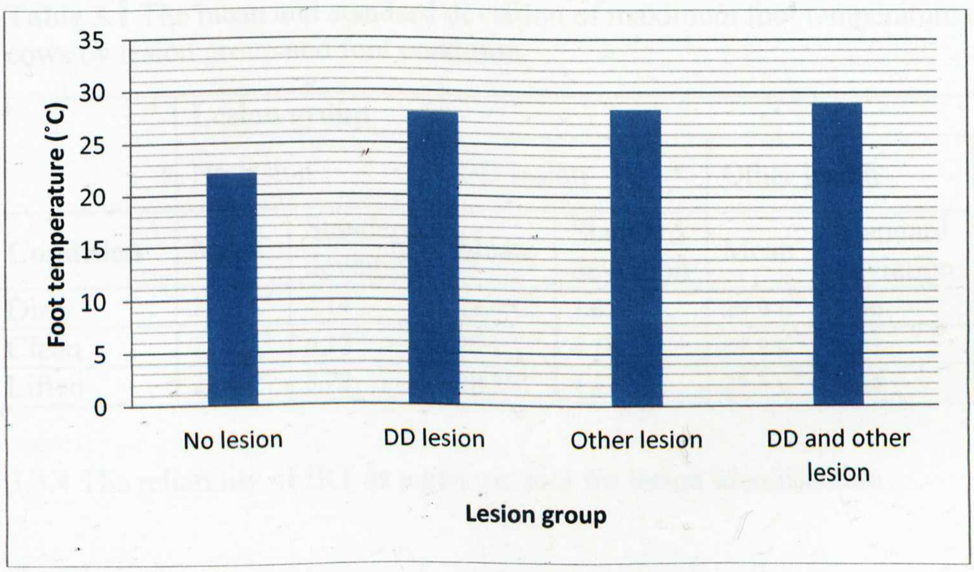


Figure 3.9 Mean maximum foot temperature for each lesion group.

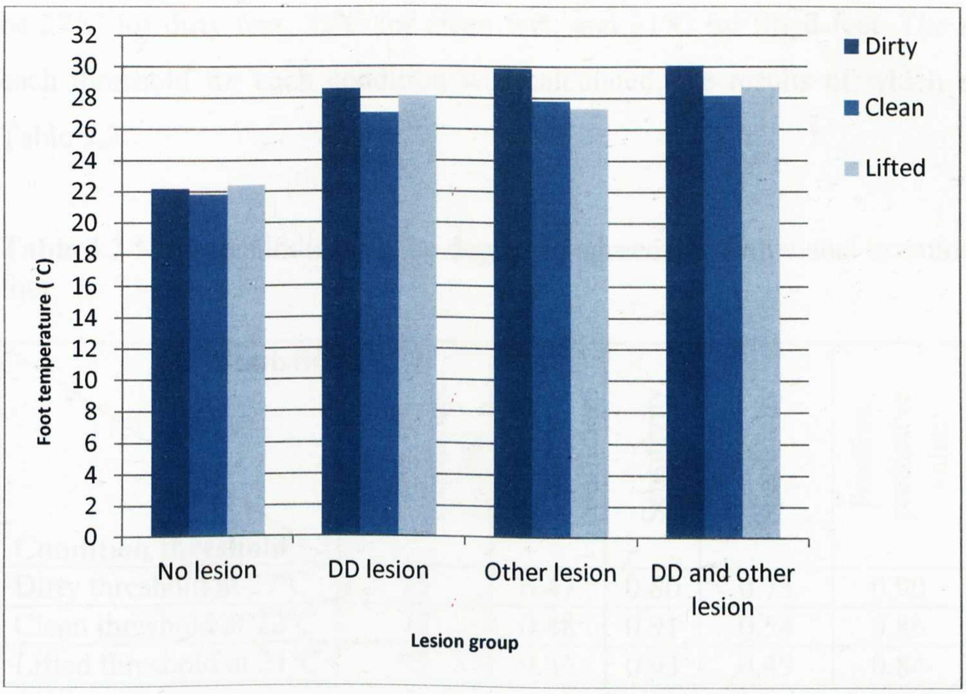


Figure 3.10 Mean maximum foot temperature in each lesion group under each foot condition (dirty, clean and lifted).

Table 3.1 The mean and standard deviation of maximum foot temperature at the pastern for cows by lesion group and foot condition.

	Lesion group							
	No lesion		DD lesion		Other lesion		DD and other lesion	
Condition	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Dirty	22.2°C[a]	7.14	28.6°C[b]	3.67	29.9°C[b]	3.36	30.1°C[b]	3.28
Clean	21.8°C[a]	6.17	27.1°C[b]	4.18	27.8°C[b]	4.11	28.2°C[b]	3.15
Lifted	22.4°C[a]	5.72	28.1°C[b]	4.47	27.3°C[b]	4.86	28.7°C[b]	3.65

3.3.4 The reliability of IRT as a generic tool for lesion identification

Feet with any combination of lesion(s) (groups 2-4, n = 123) were combined to create a lesion group compared with feet with no lesions (group 1, n = 41) and threshold temperatures were set to investigate the reliability of using a threshold foot temperature as a predictor of feet with and without a lesions. The presence or absence of any lesion based on visual examination of the lifted foot was used to assess the percentage agreement of detection using temperatures based on varying thresholds until the highest agreement was found. Agreement of less than 75% was considered insufficient for clinical use (Burn et al., 2009). The optimal threshold temperatures giving highest percentage agreement for each condition were found to be 27°C for dirty feet, 22°C for clean feet, and 21°C for lifted feet. The reliability of using each threshold for each condition was calculated, the results of which are summarised in Table 3.2.

Table 3.2 Measures indicating the degree of agreement with visual examination of the lifted foot.

Statistic / Condition threshold	Observed Disease Prevalence (%)	Cohen's Kappa coefficient	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Percentage agreement (%)
Dirty threshold at 27°C	75	0.47	0.80	0.73	0.90	0.55	79
Clean threshold at 22°C	75	0.48	0.91	0.54	0.86	0.67	82
Lifted threshold at 21°C	75	0.46	0.93	0.49	0.84	0.69	82

The observed prevalence of lesions was unbalanced (75%), meaning that the probability of agreeing by chance was increased. An observed prevalence below 25% is considered well balanced (Burn et al., 2009). Despite this, moderate agreement was found. It is worth noting that as the percentage agreement increases, the degree of population imbalance that can be tolerated for the given Kappa thresholds increases. Where percentage agreement is 75 or 80%, it is not possible to obtain Kappa values above 0.40 or 0.58, respectively (Burn et al., 2009). Kappa values above 0.40 indicate moderate agreement which is clinically useful (Landis and Koch, 1977; Sim and Wright, 2005), and temperature thresholds under each condition exceeded this criterion.

In this study the observed prevalence is considered high at 75% which means there is a greater confidence that a positive result is correct, and a lesser confidence that a negative result is correct. For example, the positive predictive value for lesion detection while feet were dirty was 90%; however the negative predictive value was 55%. After cleaning the feet, the positive predictive value for lesion detection was 86% in the standing foot and 84% in the lifted foot, with a negative predictive value of 67% in the standing foot and 69% in the lifted foot.

Setting the threshold temperature at 27°C for dirty feet identified 80% of lesions correctly and 73% of feet without lesions correctly. However, cleaning the feet increased the sensitivity of the test but lowered the specificity. Setting the threshold temperature at 22°C for clean feet correctly identified 91% of lesions but only 54% of feet without lesions. Similarly, lifted feet with a threshold temperature of 21°C identified 93% of feet with lesions correctly, but only 49% of feet without lesions.

The sensitivity and specificity of different temperature thresholds for dirty, clean and lifted feet is presented in a receiver operating characteristic curve (Figure 3.11). This demonstrates that as feet are cleaned and the temperature threshold lowers the rate of false positives rise by two and half times more than the rate of true positives. Figure 3.11 therefore indicates that a good combination of sensitivity and specificity would be achieved using IRT with dirty feet at a 27°C threshold.

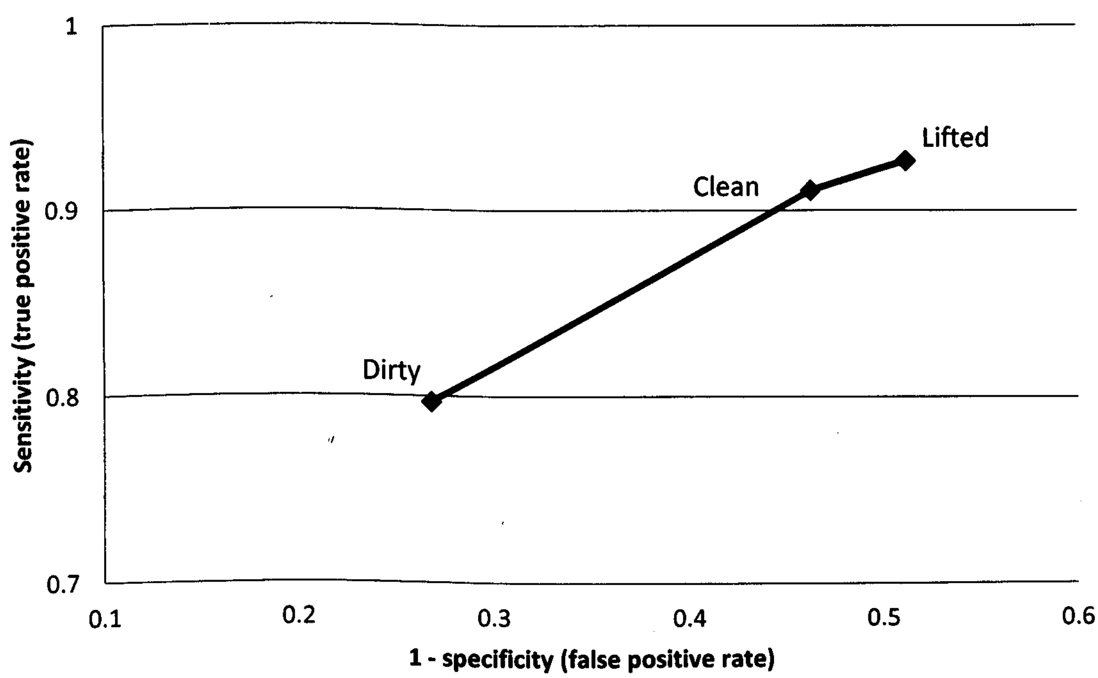


Figure 3.11 Receiver operating curve for lesion detection using different temperature thresholds under each foot condition.

3.4 Discussion

The aim of this study was to investigate whether IRT could be used to detect feet with DD. However, it was found that compared to feet without lesions, both skin (DD) lesions and other lesions cause a localised inflammatory response (of the integument) which was evidenced by an elevated skin temperature at the pastern. As there was no significant difference in specific temperature between feet with different lesion pathologies, IRT has no potential as a diagnostic test but its potential as a generic detection tool was examined. The reliability of using IRT based on a threshold temperature above which feet with lesions could be identified was investigated.

The reliability determined by Cohen's kappa coefficient between temperature thresholds and the lifted foot inspection met moderate agreement. The high sensitivity and positive predictive values suggest that assigning a threshold temperature as a critical cut-off between feet with and without lesions, can identify a substantial degree of true positives. However the lower specificity and negative predictive values indicate that threshold temperature classifies a number of lesion free feet as having lesions (false positives). This can be explained by a higher degree of variation in the temperature of feet with no lesions compared to feet with lesions. Cows with no visible lesions but elevated foot temperature may be developing lesions that cannot yet be seen.

Sensitivity and specificity are not independent, and the relative importance of the measures depends on the purpose of the test itself (Petrie and Watson, 1999). The sensitivity and the specificity of IRT may be altered by raising or lowering the threshold temperature, which determines whether the test result is positive or negative. For example, in a large population with high disease prevalence which warrants herd level treatment, it may be more practical to identify and isolate animals which are disease free. In this case a test with a high specificity would be required. Here we are concerned with identifying animals with lesions in order to treat them. Therefore a high sensitivity is more important than a high specificity.

Previous research has suggested that ambient and core body temperature (Hurnik et al., 1985) can affect the surface temperature recorded by IRT. However this study found that skin temperature measured at the udder had no association with foot temperature. Although there was a small positive correlation between ambient temperature and foot temperature, this could only account for 8.2%, 9.3% and 5.7% of the variance in foot temperature explained for dirty, clean and lifted feet, respectively. Therefore foot temperature was not adjusted for ambient temperature (Field, 2009).

Parmer (1981) found that dirt influences the reliability of thermography by affecting the surface's ability to radiate absorbed energy (emissivity) and to conduct heat (conductivity). Cleaning cows' feet with water had a cooling effect on the foot temperature recorded at the pastern. The effect of washing the feet could be controlled for in future by waiting for a standard period of time after washing before measuring the temperature of the foot. This effect can be suggested by the temperatures taken of the lifted cleaned feet. These temperatures were taken several minutes after washing and were found to rise slightly compared to the lifted standing foot temperature, which was taken immediately after washing. In order to control for cleaning of the feet, standardising the time delay between cleaning and taking the temperature measurement is recommended.

Despite cleaning the feet, the temperature differences between feet with and without lesions remained (see Figure 3.10). This is due to the relative temperature differences across conditions. However, dirt had an impact on the threshold temperature, above which feet were identified with lesions (Table 3.2 and Figure 3.10). The sensitivity of identifying lesions increased from 80% for dirty feet to 91% after cleaning the feet and 93% in a clean lifted foot. The specificity decreased from 73% in dirty feet to 54% after cleaning the feet and 49% with a lifted foot. Cleaning feet and lowering the temperature threshold from 27°C to 22°C increased the reliability of detecting feet with lesions correctly, but also increased the likelihood that feet without lesions will also be identified as positive. After cleaning the feet the rate of false positives rose by two and half times more than the rate of true positives. The operation receiver curve (Figure 3.11) demonstrates that the optimal trade off between sensitivity and specificity can be reached without having to either clean or lift the feet. Practically this enables a rapid detection method with minimum disturbance to the daily routine and animal.

Currently locomotion scoring is the recognised outcome measure for assessing lameness for research purposes and identifying cows for treatment in a commercial setting (Whay, 2002a). Routinely locomotion scoring a herd of cows is an inherently subjective process (Whay, 2002a; Telezhenko, 2005) which requires regular observation that is, both logistically and economically challenging in practice. Cows with mild lameness can, in the absence of regular scoring, be left undiagnosed until the problem has become severe. Furthermore, it has been suggested that infectious diseases such as digital dermatitis can affect locomotion inconsistently, lesions not always being accompanied by obvious lameness (Vink, 2006); a subject which will be discussed in the next chapter. The advent of technology such as IRT could automate routine detection of diseased feet for closer inspection and treatment in the crush. Screening feet on a regular basis using a computerised IRT system, which would identify individual cows or their feet when they exceed a temperature threshold, would allow farmers and herdsman more time to concentrate on treatment. Best practice could integrate IRT recordings into the daily routine, in the milking parlour or at the feed rail.

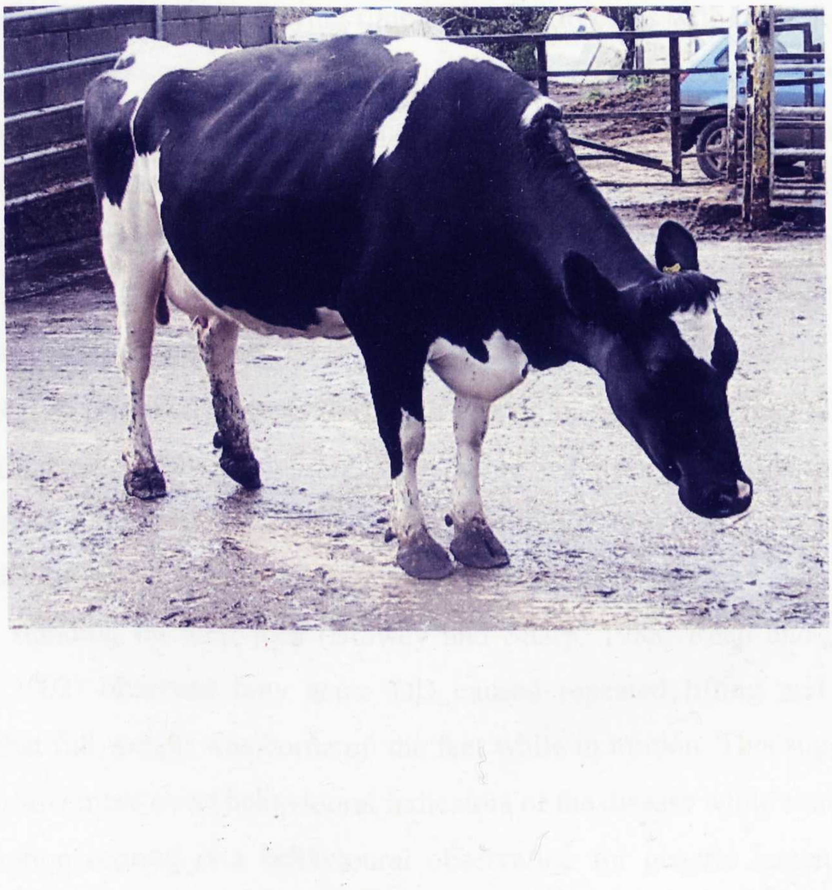
However, like all novel tools in the early stages of development, this technology is expensive and therefore unable in its current form to be marketed at a farm level. This study suggests that IRT has the potential for generic lesion detection rather than diagnosis. The technique has the advantage that it can be used with little or no restraint of the animal and its efficiency allows serial evaluations that can help monitor response to treatment with relative ease (Turner et al., 1989). Research into early detection of mastitis has suggested that IRT has the potential to identify physiological changes before they appear locally as clinical signs (Scott et al., 2000). The inflammatory response which is reflected in surface foot temperature is likely to vary with the stage and severity of cases, a subject which needs further investigation. Future research should focus on following the development of lesion cases longitudinally to establish threshold temperatures for early treatment interventions and to quantify the effectiveness of these by using IRT to follow recovery and reoccurrence.

3.5 Conclusion

Lesions of both the claw and skin (DD) caused inflammatory responses associated with elevated skin temperature at the pastern, compared to feet with no lesions. This study established the potential of IRT as a reliable, practical tool for generic lesion detection, without having to clean or lift the foot, although expense prevents farm use at present. Future work should investigate the reliability of using a hand herd infrared thermometer for the detection of temperature changes associated with foot lesions.

Chapter 4

The use of behavioural observations to identify measures associated with specific foot lesions in dairy cattle



4.1 Introduction

Painless and unrestricted mobility is essential for cows to satisfy their biological and social needs (Somers et al., 2005a). The welfare implications of impaired locomotion are considerable (Whay et al., 1998), in particular pain and discomfort associated with lameness can be severe. Impaired locomotion is a behavioural indicator for the degree of pain and discomfort caused by claw disorders (Whay et al., 1998). Frustration can result from suppression of behavioural activities due to reduced mobility (Galindo and Bloom, 2000).

The effect of DD on locomotion and behaviour was first investigated by Somers and others in 2004 (Somers et al., 2004). They found that severely affected cows stood for longer in cubicles, and had a reduced total lying time compared to cows with no lesions. As a result they concluded that discomfort or pain associated with DD can reduce cow mobility and lying behaviour, which have potential consequences for feeding, resting and ruminating behaviour. A disruption to lying behaviour can also have consequences for social behaviour and pecking order (Fregonesi and Leaver, 2001). However, more recently research has suggested that DD is not always accompanied by obvious lameness (Vink, 2006) which may lead to cases persisting undetected.

Lameness is frequently assessed while a cow is in motion but may also be apparent when a cow is standing still. Cows are often witnessed lifting the affected foot and are reluctant to move (Whay, 1997). Bassett et al., (1990) observed how cows with DD frequently shake the affected limb. Additionally, cows are seen shifting weight away from the lesion site by standing on their toes (Blowey and Sharp, 1988; Read and Walker, 1998). O'Callaghan (2002) observed how acute DD caused repeated lifting and paddling at a standstill but that full weight was borne on the feet while in motion. This suggests that cows with DD may show more overt behavioural indicators of the disease while standing still.

Locomotion scoring is a behavioural observation for generic lameness assessment within a research setting and increasingly in industry (Whay, 2002a). Behavioural observations are used progressively more as outcome measures to assess the welfare of farm animals in a research setting, intended for integration into welfare assurance schemes (Wemelsfelder and Lawrence, 2001). However research has yet to investigate whether cows display behaviours associated with specific foot lesions, distinguishable from other lesion pathologies. For example, behaviour associated with DD only, may be utilised to develop practical lesion specific detection tools.

An ethogram can be defined in several ways. "A category of descriptions of the discrete, species-typical behaviour patterns that form the basic behavioural repertoire of the species." (Martin and Bateson, 2007) and "a pictorial representation of the frequency with which one activity follows another" (McFarland, 2006). The behavioural patterns of an animal have to be defined before one can represent the frequencies with which they follow one another (Mononen, 2008). However no published papers currently exist which describe dairy cow behaviour. Comprehensive and detailed ethograms can be utilised to survey farm animal behaviour, as an indicator of welfare and disease.

The study reported in this chapter used a novel ethogram and adapted locomotion scoring system to establish how DD and other lesions affect cows' behaviour both at a standstill and while in motion. The aim of this study was to identify which aspects of behaviour are specifically associated with DD, in order to investigate whether behavioural observation in a standing cow may be a tool for on farm disease detection. An ethogram was developed and used to assess how DD and other lesions affect the behaviours performed by cows. Locomotion scoring was used to assess the effect DD and other lesions have on gait. A gold standard lesion inspection in the crush allowed behaviour and locomotion to be related to the lesions or combination of lesions on the cattle's feet.

4.2 Method

4.2.1 Cow selection

The study was carried out on four dairy farms served by the University of Bristol Farm Animal Practice in Somerset (see section 2.2.1) and cows were selected according to the method described in section 2.2.2.

4.2.2 Ethogram construction

When developing an ethogram, it is necessary to distinguish between two fundamental types of behaviour pattern. Events are behaviour patterns of relatively short duration, such as discrete body movements or vocalisations, which can be approximated as points in time. Behavioural events are measured in terms of their frequency of occurrence. States are behaviour patterns of relatively long duration, such as prolonged activities, body posture or proximity. Behavioural states are measured in duration.

The present ethogram was developed by observing and recording cow behaviour within the milking group at the university farm. Cows were observed continuously for two hours between 10-12am in the cubicle housing unit. The researcher stood behind a gate in the corner of a housing unit, in order to minimise disturbance to the herd. Ten cows within viewing range were observed for state and event behaviours. Recorded behaviours were then grouped into types of behaviour. Types of event behaviours include *Movement, Foot, Social, Grooming, Oral/anal/nasal, Head, Body, and Tail.* Types of postural state behaviour include *Ear, Eye, Head, Back, Leg, Tail and Body position.* All behaviours were then defined to form a complete list of behaviours (Appendix 4.1). The ethogram was practised on a further five cows for ten minutes at the same time of day, in order to add or amend behaviours and descriptors. Event and state behaviours, under types of behaviour, were tabulated to create practical data collection sheets (Appendix 4.2 and 4.3).

4.2.3 Behavioural observation (Ethogram)

At the inspection visit on the morning following selection, before cows were moved into the crush (see section 2.2.2), four cows were placed together in the collecting yard with access to water and left for five minutes to acclimatise to their surroundings. Feeding behaviour could not be observed in this situation. The researcher then observed each cow, one by one, for a period of ten minutes (per cow) from a position outside the yard to avoid disturbing the group. The frequency of event behaviours was recorded continuously. Time was kept by a GYMBOSS timer. This was set to vibrate every minute for ten seconds during which time the postural behaviours were recorded using scan sampling.

4.2.4 Locomotion scoring

Once all behavioural observations were completed the researcher entered the collecting yard and walked each cow in turn in order to view her locomotion from behind and the side. The locomotion was scored according to the system described in Table 4.1. The scale was adapted from Barker et al., (2008) four point system by spitting *Score 1* into 2 categories to differentiate between the affect an infectious skin lesion such as DD has on locomotion compared to a claw horn lesion.

Table 4.1 Locomotion scoring system adapted from Barker et al., (2008).

Score 0 Good locomotion – not lame Limbs move smoothly and freely in a straight and forward line, hind limbs imprint where front limbs fell, no reluctance to move forward.	
Score 1A Not lame – abnormal gait Stride length consistently shorter than expected where hind limbs do not imprint on where front feet fell due to widening, narrowing or shortening.	
Score 1B Tender foot – without limp Hind limbs do not imprint on where front feet fell, cow walks cautiously or slowly due to soft placement of feet suggesting tenderness, however no obvious limp.	
Score 2 Lame – limb(s) identified as bearing less weight or force Consistently shortened stride length with identified limb placed slowly, uneven rhythm of steps where sound leg swings more quickly than lame limb, limbs may swing out to the side and spine is often arched and head may nod.	
Score 3 Severely lame Limb(s) instantly identifiable with marked limp where speed of walk severely impaired. Reluctant to move and stops to rest, very obvious head nodding/swinging, low head carriage, very uneven rhythm of steps and an arched spine.	

4.2.5 Lesion inspection in the crush

Lesion data was obtained in the crush as described in section 3.2.5.

4.2.6 Classification of cows according to lesion type

The data were analysed at a cow level. The data from eighty four cows were used. Two cows were removed from the dataset due to missing data. Each cow was allocated to a group according to the combination of specific lesions present on one or both of the hind feet. The four groups consisted of group one = 13 control cows with no lesions, group two = 14 cows with sole haemorrhage only, group three = 25 cows with DD only, and group four = 32 cows with both DD and other lesion(s) (sole haemorrhage, sole ulcer, white line, or interdigital growth).

4.2.7 Data analysis

Raw data were entered into Excel then transferred into SPSS Version 16.0 for analysis. Descriptive statistics were calculated for behaviours, locomotion scores and lesion data. The Kolmogorov-Smirnoff test was used to test variables for normality, supported by skewness and kurtosis, histograms, normal Q-Q Plots and Detrended Normal Q-Q Plots. None of the behaviours or locomotion scores were normally distributed. Therefore lesion groups were compared for differences in locomotion scores and behaviours using the Kruskal Wallis and Mann Whitney U Test. The level of significance was set at $p < 0.05$.

4.3 Results

4.3.1 Frequency of behaviours observed

A number of behaviours were not observed at all or frequently enough to enable statistical comparison. Table 4.2 summarises the frequency of behaviours observed overall. As there were a number of behaviours observed, only behaviours with significant differences between lesion types are reported in full here.

Table 4.2 The total number of times each behaviour was observed across all 84 cows within a 10 minute observation period. Behaviours highlighted in green never occurred. Behaviours highlighted in blue occurred too infrequently to be analysable. Behaviours highlighted in turquoise did not occur significantly differently between lesion types. Behaviours highlighted in yellow occurred significantly different between lesion types. FL = Front left foot, FR = Front right foot, HL = Hind left foot, HR = Hind right foot. Front = both front feet, Hind = both hind feet.

EVENT BEHAVIOURS	BODY MOVEMENT					BODY					
	Lying down	Rising up	Walking forwards	Walking backwards	Sideways move	Skin twitch	Skin quiver	Body rock	Body stretch	Stomach retch	Elimination
Frequency	0	0	414	73	37	23	0	2	1	68	23

EVENT BEHAVIOURS	SOCIAL								GROOMING		
	Tending	Jarring	Herding	Barge	Greet	Bulling	Flight	Kick	Body/head scratch	Self groom	Pairwise grooming
Frequency	10	20	9	30	18	0	0	3	77	49	2

EVENT BEHAVIOURS	LIMB MOVEMENT																			
	Tip toes				Resting feet				Limb swing				Limb Kick				Slip/stumble			
	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR
Frequency	2	5	19	32	1	0	55	61	0	0	0	0	1	1	8	1	1	1	1	1

EVENT BEHAVIOURS	LIMB MOVEMENT																	
	Stamping				Pawing				Shaking				Lifting foot				Weight Shifting	
	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	Front	Hind
Frequency	0	0	0	1	1	0	0	0	0	0	17	5	52	85	274	314	24	152

EVENT BEHAVIOURS	ORAL/VOCAL										
	Sniff/smell	Lick	Snort	Cough	Pant	Flehmen	Feeding	Ruminate	Regurgitate	Drink	Bellow
Frequency	284	55	15	47	0	6	7	87	68	7	259

EVENT BEHAVIOURS	HEAD						TAIL	
	Neck stretch	Explore environment	Bobbing	Flick	Roll	Turn	Swishing	Flick
Frequency	56	129	4	37	6	829	126	267

POSTURAL BEHAVIOURS	EARS			EYES		HEAD				BACK	
	Forwards	Backwards	Sideways	Open	Closed	Risen	Level	Down	Turned	Flat	Arched
Frequency	128	306	436	868	2	136	188	360	186	775	95

POSTURAL BEHAVIOURS	LIMB					TAIL				BODY	
	Even weight	Front left	Front right	Hind left	Hind right	Relaxed	Tucked	Swished	Out	Standing	Laid down
Frequency	640	0	0	91	127	700	46	38	86	870	0

4.3.2 The relationship between behaviours and lesion type

Figure 4.1 illustrates the significant differences in event behaviours between lesion types. Cows explore their environment by moving towards another object to look, sniff, smell or lick it differently between lesion type ($H_3 = 12.98$, $p < 0.01$). Cows with DD performed significantly fewer exploratory behaviours (median = 1, range = 5,) than cows without any lesions (median = 2, range = 6, Z = -2.69, p <0.01). There were no other significance differences between lesion groups.

There was a significant difference between foot lesions in the number of times cows rest their hind feet by taking weight off one of their hind limbs where weight is born on the other feet ($H_3 = 18.27$, $p < 0.001$). Cows with DD only (median = 1, range = 7, Z = -2.86, p <0.01) and both DD and another lesion (median = 1, range = 9, Z = -2.75, p < 0.01) rested their hind feet significantly more than cows with no lesions (median = 0.00, range = 2). Additionally, cows with sole haemorrhage rested their hind feet significantly less (median = 0, range = 2) than cows with DD (median = 1, range = 7, Z = -3.27, p < 0.01), and both DD and another lesion (median = 1, range = 9, Z = -3.13, p < 0.01). The frequency of lifting hind feet when they raise a hind limb off the ground with reluctance to place back down on the floor differed significantly between cows with different foot lesions ($H_3 = 13.73$, $p < 0.01$). Cows with DD only (median = 5, range = 44, Z = -2.18, p < 0.05) and both DD and another lesion (median = 8, range ≑ 57 Z = -3.25, p < 0.001) lifted their hind feet significantly more than cows with no lesions (median = 1, range = 9). In addition, cows with digital dermatitis only (median = 5, range = 44, Z = -3.27, p < 0.001) and cows with DD and another lesion (median =8, range = 57, Z = -2.62, p < 0.01) lifted their feet significantly more than cows with sole haemorrhage (median = 2, range = 17).

The frequency of repetitively chewing forage differs significantly depending on cows' hoof health ($H_3 = 12.98$, $p < 0.01$). Cows with DD only (median = 0, range = 3, Z = -2.18, p < 0.001), sole haemorrhage (median = 0, range = 5, Z = -2.41, p < 0.05), and both DD and another lesion (median = 0, range = 4, Z = -3.01, p < 0.01) all ruminated significantly less than cows with no lesions (median = 1, range = 7). The frequency of regurgitation differed significantly depending on cows' hoof health ($H_3 = 14.6$, $p < 0.01$). It was found that cows with sole haemorrhage (median = 0.50, range = 3), DD (median = 0, range = 5, Z = -2.68, p <0.001), and those with both DD and claw horn lesions (median = 0, range = 3, Z = -3.52, p < 0.001) regurgitate significantly less than cows with no hoof lesions (median = 1, range = 6).

In addition, cows with both DD and a claw horn lesion regurgitate significantly less (median = 0, range 3) than cows with sole haemorrhage (median = 0.5, range = 3, Z = 2.18, p <0.05).

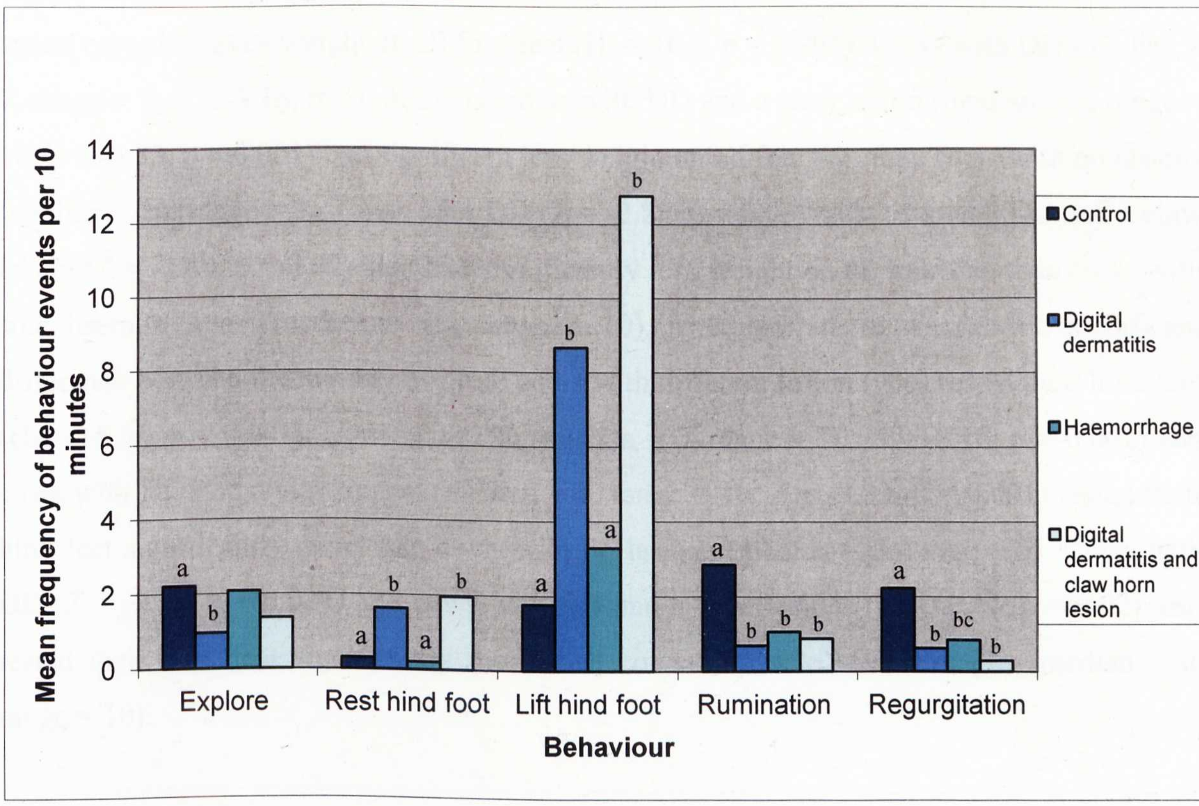


Figure 4.1 Behavioural events found to have significant differences in frequencies between lesion groups over a ten minutes observation period. Values with different superscripts are significantly difference from each other.

Figure 4.2 illustrates the frequency of significant postural behaviours recorded at 1 minute intervals during the behavioural observations. There was a significant difference between the number of times cows with different lesion types presented flat backs ($H_3 = 9.84$, $p = 0.02$). Cows with no lesions (median = 10, range = 0) had significantly more flat backs than cows with DD (median = 10, range = 1, $Z = -2.15$, $p = 0.03$) and cows with DD and a claw lesion (median = 10, range = 10, $Z = -2.47$, $p = 0.014$). Furthermore, cows with sole haemorrhage (median = 10, range = 1) had significantly more flat backs than cows with DD and a claw lesion (median = 10, range = 10, $Z = -2.14$, $p = 0.03$). There was therefore a significant difference between the number of times cows with different lesion types had arched backs ($H_3 = 9.84$, $p = 0.02$). Cows with DD (median = 0, range = 10, $Z = -2.15$, $p = 0.032$) and cows with DD and a claw lesion (median = 0, range = 10, $Z = -2.465$, $p = 0.014$) had significant more arched backs than cows with no lesions (median = 0, range = 0). Cows with sole haemorrhages (median = 0, range = 1) had significantly less arched backs than cows with DD and a claw horn lesion (median = 0, range = 10, $Z = -2.14$, $p = 0.032$).

There was a significant difference between the number of times cows with different lesion types had even weight on all four feet ($H_3 = 16.6$, $p < 0.001$). Cows with DD (median = 7, range = 7, $Z = -3.16$, $p = 0.002$) and cows with DD and a claw lesion (median = 7, range = 10, $Z = -3.33$, $p < 0.001$) had significant less weight on all four feet than cows with no lesions (median = 10, range = 3). Cows with DD ($Z = -2.25$, $p = 0.03$) and cows with DD and a claw lesion ($Z = -2.44$, $p = 0.02$) also had significantly less weight on all four feet than cows with sole haemorrhages (median = 10, range = 10). Therefore, there was also a significant difference between the number of times cows with different lesion types rested their hind feet ($H_3 = 16.56$, $p < 0.001$). Cows with DD (median = 0, range = 10, $Z = -3.16$, $p = 0.002$) and cows with DD and a claw lesion (median = 3, range = 10, $Z = -3.33$, $p = 0.001$) rested their hind feet significantly more than cows with no lesions (median = 0, range = 3). Cows with DD ($Z = -2.25$, $p = 0.024$) and cows with DD and a claw lesions ($Z = -2.44$, $p = 0.02$) also rested their hind feet significantly more than cows with sole haemorrhages (median = 0, range = 10).

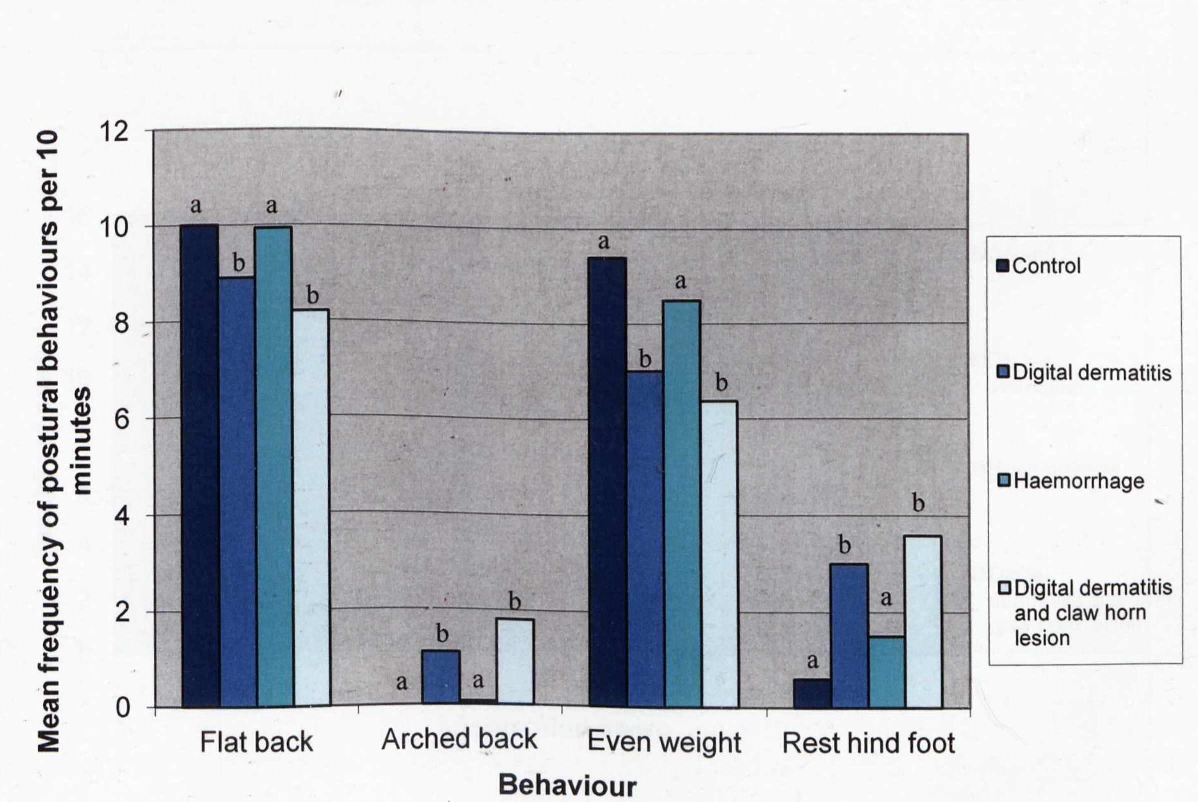


Figure 4.2 Postural behaviours found to have significant differences in frequencies between lesion groups over a ten minutes observation period. Values with different superscripts are significantly difference from each other.

4.3.3 The relationship between locomotion scoring and lesion type

No cows in this study had a locomotion score of 3 (severely lame).The results show that 28% of cows with DD alone had a score of 1A (abnormal gait – not lame) and 52% had a score of 1B (tender foot – without limp). Using the current scoring system where cows are classed as lame with a score 2 or above, 80% of cows with DD alone would not be considered lame. Only 20% of the cows with DD alone had a score of 2 (lame), whereas 44% of cows with DD and another lesion classify as lame (Figure 4.3).

Figure 4.3 illustrates the number of cows in each lesion group with each locomotion score. Figure 4.4 illustrates that the severity of locomotion scores increased with number of lesions present ($H_3 = 38.86$, $p < 0.001$). Compared to cows without lesions (median = 0, range = 1), cows with DD (median = 1.5, range = 1, $Z = -4.91$, $p < 0.001$), sole haemorrhage (median = 1, range = 1, $Z = -4.02$, $p < 0.001$), and both DD and another lesion (median = 1.5, range = 2, $Z = -4.99$, $p < 0.001$) had significantly higher locomotion scores. In addition, cows with DD (median = 1.5, range = 1, $Z = -2.75$, $p < 0.01$) and both DD and another lesion(s) (median = 1.5, range = 2, $Z = -3.36$, $p < 0.001$) had significantly higher locomotion scores than cows with sole haemorrhage (median = 1, range = 1).

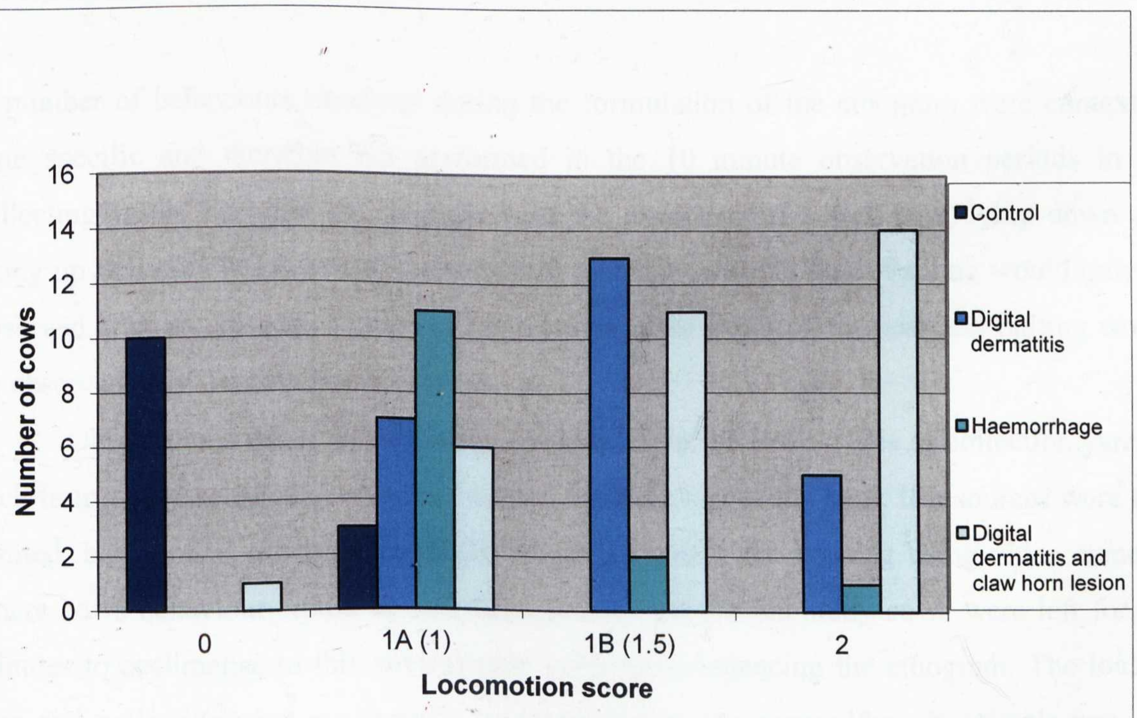


Figure 4.3 The distribution of locomotion scores for cows with different lesions: cows with no lesions (control), cows with sole haemorrhage, cows with DD, and cows with both DD and a claw horn lesion.

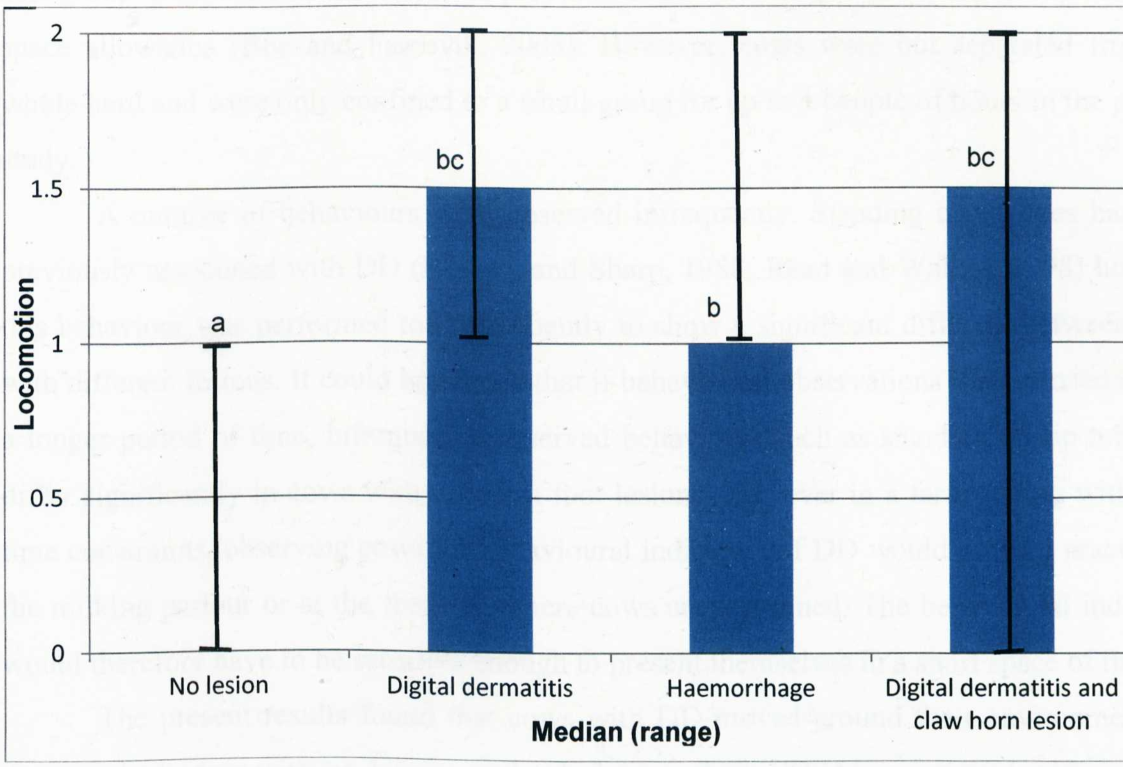


Figure 4.4 The median and range of locomotion scores between lesion types. Bars indicate range of scores. Values with different superscripts are significantly different from each other.

4.4 Discussion

A number of behaviours observed during the formulation of the ethogram were context or time specific and therefore not performed in the 10 minute observation periods in the collecting yards. For example, perhaps with the exception of a sick cow, lying down and rising up will only be observed in the cubicle housing or in the field. Panting would only be observed after an episode of stress or exercise or in the event of sickness and bulling would be observed only if a cow was in oestrus.

Observations were carried out for ten minutes in the loafing area or collection yard on each farm where selected cows were isolated from the rest of the herd. If resources were less limited, behavioural observations could be carried out in the housing using video cameras where cows behaviour would be less disturbed. In the present study cows were left for ten minutes to acclimatise to this environment prior to commencing the ethogram. The loafing area and collecting yard are familiar environments to the cows although animals may not have experience of being separated from the rest of the herd and isolated in a small group, except if they have been previously needed treatment. The impact prolonged isolation from the rest of the herd has been determined by a number of factors: the social status of each cow and group composition, the effect of previous experience of isolation, the group size, and space allowance (Boe and Faerevik, 2003). However, cows were not separated from the whole herd and were only confined to a small group for up to a couple of hours in the present study.

A number of behaviours were observed infrequently. Standing on tip toes has been previously associated with DD (Blowey and Sharp, 1988; Read and Walker, 1998) however this behaviour was performed too infrequently to show a significant different between cows with different lesions. It could be argued that if behavioural observations were carried out for a longer period of time, infrequently observed behaviours such as standing on tip toes may differ significantly in cows with different foot lesions. However in a farm setting with daily time constraints, observing cows for behavioural indicators of DD would only be practical in the milking parlour or at the feed rail where cows are restrained. The behavioural indicators would therefore have to be sensitive enough to present themselves in a short space of time.

The present results found that cows with DD moved around their environment less compared to cows with no lesions and sole haemorrhage. This is consistent with previous research which found that DD reduces cow mobility (Somers et al., 2004). A reduction in mobility found in the present study can be attributed to DD as the frequency of movement did not differ significantly compared to cows with both DD and another lesion. A reduction in mobility has direct consequences for feeding behaviour (Singh et al., 1993; Somers et al., 2004). The present study found that cows with one or more lesion had a significant reduction in the frequency and occurrence of regurgitation and rumination, compared to cows with no lesions.

To the author's knowledge, this is the first study to relate reduced digestive behaviours of ruminating and regurgitating to specific lesion pathologies. Authors have previously found that generic lameness is associated with a reduction in feeding (Singh et al., 1993). Amory et al., (2008) established that cows with sole ulcers and white line disease have a reduced milk yield, and cows with DD have an increased milk yield after treatment. The present study found that regardless of type or severity of lesion, on average cows with any lesion were associated with a reduction in ruminating and regurgitating. These results have direct implications for dairy cattle health and welfare and productivity.

Previous research has suggested that cows with acute DD lift and paddle their feet while at a standstill, yet bear full weight on an affected limb when in motion (O'Callaghan, 2002). This study suggests that cows with DD and both DD and another lesion lift their hind feet substantially more than cows with no lesions or with sole haemorrhage. Resting of the hind feet was also associated with DD only as this behaviour did not increase significantly in cows with both digital dermatitis and another lesion. Lifting and resting of the hind feet can be explained by a cow's attempt to shift weight away from the lesion site due to the pain and discomfort associated with putting pressure on a skin lesion (Blowey and Sharp, 1988; Read and Walker, 1998).

The frequency of postural behaviours recorded at 1 minute intervals during the behavioural observations further supported the finding that cows with DD and DD and a claw horn lesion rested their hind feet significantly more than cows with sole haemorrhages and cows with no lesions. Furthermore, cows with DD and DD and a claw horn lesion were found to arch their backs significantly more than cows with no lesions or a sole haemorrhage.

In order for behavioural indicators to be useful measures of disease detection, their sensitivity, accuracy and reliability over time and across farms needs to be assessed (Mononen, 2008). For example, in order for lifting and resting of the hind feet to be practically useful indicators, these measures need to be reliably associated with DD, as well as obtaining acceptable repeatability over time, and occurring consistently throughout the day in order to be observed within the time constraints of a limited observation period during a ten minute milking. Lifting the hind feet was far more frequently observed than resting a hind foot in the ten minute observation period, however resting of the hind foot was also detected as a postural behaviour associated with DD during one minute intervals, along with arching of the back. The reliability of these measures needs to be established in order to determine their use for farmers and herdsmen as practical indicators of disease.

This study was able to find a significant difference in the frequency of five behaviours within eighty four cows during a ten minute observation period. However these results have to be viewed within the context of the small sample size and the number of behaviours recorded which can affect the power of the test results. This study measured 100 behaviours in 84 cows; therefore it is possible that five behaviours occurred by chance (at the 0.05 significance level). However, overall, the difference in frequency of resting the feet was significantly different across lesion groups at the 0.001 level where the probability of an effect occurring by chance is 1 in 1000. The difference in frequency of ruminating, regurgitating, lifting the feet and exploring behaviour between lesion groups was significant at the 0.01 where the probability of an effect occurring by chance is 1 in 100.

In order to increase the power of the test in future studies, the criterion of significance can be increased. Sample size determines the amount of sampling error inherent in a test result where effects are harder to detect in smaller samples. Increasing the sample size and making power calculations to ensure a large enough sample for statistical power is important.

This study suggests there maybe potential to use an ethogram to identify behaviours associated with specific diseases. Future research should focus on assessing the reliability (sensitivity and specificity) of behavioural indicators to detect DD cases at the feed rail or in the milking parlour, as an alternative means of identifying individual cows in need of inspection. Automated methods of continuously measuring and interpreting each animal's health and welfare status would ensure that stockman time and skill is directed at the animals in most need of attention and treatment. The methods farm staff currently use to identify DD on farm will be the subject of chapter 5.

Previous research has varied in reports of the effect of DD on locomotion (Clarkson et al., 1996; Winkler and Willen, 2001; Laven and Proven, 2000; Somers et al., 2004, Vink, 2006). If locomotion is only affected in severe cases, this may lead to an underestimation of the disease and delayed treatment intervention. This would have serious implications for how the locomotion score results are interpreted in relation to foot disease morbidity. The locomotion score of a cow with DD is likely to be affected by the time it is carried out, in relation to disease progression, as well as treatment. The present study investigated the use of locomotion scoring to identify cows with different lesion pathologies. As expected, the majority of cows with no lesions (77%) had sound locomotion, and the majority of cows with sole haemorrhage had imperfect locomotion (78%). Cows with sole haemorrhage had a significantly higher locomotion score than cows with no lesions, even though this group represented a mild form of claw horn lesion.

Thirty two cows that had DD also had other lesions, such as sole ulcers, white line disease and interdigital growths. It was found that cows with DD, and both DD and another lesion had significantly higher locomotion scores than cows with no lesions or sole haemorrhage. The most frequent score for cows with DD was the tender, slow footed and soft placement of feet category (52% at Score 1B). This is an important distinction from the abnormal gait category, where only their stride length and not speed is compromised (28% at Score 1A).

Using the scoring system shown in Table 4.1, only cows with a score 2 or above are considered lame. Using this threshold, the present study identified 80% of cows with digital dermatitis only as non lame (scores 1A + 1B), and only classified 20% as lame (score 2). In order for locomotion scoring to identify DD, it is essential that the system is sensitive enough to identify cows with soft/tender placement of feet (1B). Therefore, using the current data, lowering the threshold for lameness to include a 1B category would identify 72% of cows with DD. Using this scoring system, no cows with any lesions would be classed as lame and two cows with sole haemorrhages would be classed as lame.

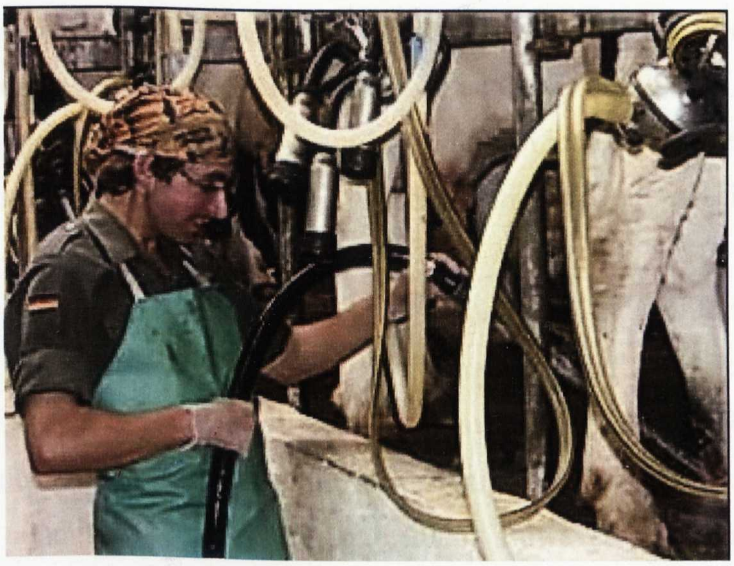
4.5 Conclusions

Regardless of severity or type, cows with foot lesions showed a substantial reduction in ruminating and regurgitating in comparison to cows with no lesions. Lifting and resting of the feet was associated with DD, the reliability of which should be assessed in order to establish the potential of these measures as behavioural indicators of the disease. Cows with DD alone are less likely to show obvious lameness, rather, a soft placement of feet suggesting tenderness. Commonly used lameness scoring systems may be less appropriate for identifying digital dermatitis compared to other lesions. Locomotion scoring can be used to detect cows with DD, providing it is sensitive enough to pick up a soft footed and tender gait, without classing cows without lesions as lame.

These results have both welfare and disease management implications for dairy herds that rely on lameness scoring as a method of detecting individual cases for treatment, or taking decisions on herd level strategies for prevention and treatment, since it is likely that the prevalence of DD is underestimated.

Chapter 5

Management decisions farmers take to prevent detect and treat digital dermatitis in England and Wales



5.1 Introduction

The prevalence and morbidity of DD is on the increase (Bell, 2006). The mean prevalence of DD in heifers across 60 farms in 2003 was forty percent, rising to fifty six percent in 2006 despite the implementation of a lameness control programme (Bell et al., 2009). This suggests that current management strategies to prevent, treat and control the disease are inadequate, and/or intervention action by farmers is insufficient. Lack of intervention uptake has been associated with the perceived time, labour and cost involved (Leach et al., 2010).

If an intervention is implemented but not perceived effective enough to warrant the investment, farmers are unlikely to sustain the action. Research has suggested that farmers underestimate the prevalence of lameness on their farms and therefore do not perceive the need to take action to reduce it (Whay, 2002b). In addition, Leach et al., (2010) found that although the average lameness prevalence measured by an independent researcher across 222 farms was thirty six percent, ninety percent of these farmers did not perceive lameness to be a major problem.

Despite the scale of the DD problem, limited published information on curative treatment of the disease is available and the information about the efficacies of commonly used treatment strategies remains ambiguous (Laven and Logue, 2006). Studies have focussed on clinical trials comparing the effectiveness of different foot bathing solutions under controlled conditions (Laven and Logue, 2006). However, research has yet to establish the effect of these approaches under commercial conditions.

The treatment options currently available to farmers consist of individual treatments with an oxytetracycline aerosol or an anti-bacterial copper sulphate based alternative, and foot bathing the whole herd (Laven and Logue, 2006). However few peer-reviewed studies reporting the effectiveness of footbathing as a treatment strategy have been published (Vink, 2006). It has been suggested that individual treatment is more effective than herd treatment (Nowrouzian and Zareii, 1998). Despite this, the use of foot bathing is widespread, as it is relatively easy and time effective to apply to the whole herd. Footbathing negates the need to identify and treat individual cases one by one (Vink, 2006). However, best practice advice regarding the optimal frequency or concentration or solutions for treatment has yet to be resolved.

It has been found that an individual application of oxytetracycline cured 87% of cases of DD and was significantly more effective than foot trimming alone or applying glutaraldehyde (Manske et al., 2002). More recently, Dopfer et al., 2011 found that topical treatment of acute lesions with oxytetracycline resulted in prompt cure within one to two days, while non-antibiotic multi-compound agents did not lead to clinical cure. However Shearer and Hernandez, 2000, found that a modified non antibiotic formulation (Victory containing reduced soluble copper and peroxide compound but with increased levels of cationic agent) appeared to be more effective than oxytetracycline as measured by signs of pain at the lesion site 7, 14, and 28 days after treatment, although lesion size did not differ between groups. The reduced efficacy of oxytetracycline was an unexpected result which the authors attributed to antibiotic resistance as the study herd had a history of long term exposure to this antibiotic as a footbathing agent. Stevancevic et al., 2009, compared the efficacy of several antiseptics (copper sulphate 8%, zinc sulphate 8%, formalin 8%, and peracetic acid 3%) for the topical treatment of DD and found that according to the presence, size and painfulness of DD lesions, zinc sulphate had the best curative effect. By day 30, the curative effect of zinc sulphate compared to the positive control of chlortetracycline did not differ (Stevancevic et al., 2009).

Antibiotic (Laven and Proven, 2000) and formalin (Holzhauer et al., 2008) footbath solutions have been reported to be effective in reducing the prevalence of DD and controlling the disease. However the use of either solution is contentious. Formalin is a potential carcinogen and can cause significant pain when applied to digital dermatitis lesions (Laven and Logue, 2006). Antibiotics are expensive, not licensed for use and place legislative restrictions on the sales of milk (Laven and Logue, 2006) furthering their unpopularity with farmers. The widespread use of antibiotics has both human and animal health issues and may lead to increased antibiotic resistance in cattle (Shearer and Hernandez, 2000).

Teixeira et al., (2010) found that the odds of DD were 1.36 times higher for cows footbathed with 5% formalin twice a week compared to a novel, commercial available disinfectant agent Dragonhyde (5%). Laven and Hunt (2002) evaluated the use of erythromycin, formalin, copper sulphate and peracetic acid and found no statistical difference in their ability to control the prevalence of DD.

Copper sulphate is an attractive non-antibiotic footbath solution for farmers as it is widely availability and easy to use. However studies have reported varying efficacy. There are also environmental and human health hazards associated with copper, a heavy metal, accumulation in the soil when the solution is disposed of (Salam and El-Fabel, 2008). Copper sulphate is also an astringent and may therefore cause pain when in contact with open DD lesions (Laven and Logue, 2006).

More recent research has suggested copper sulphate can be efficacious in reducing the prevalence of DD at concentrations of 2 to 10% (Teixiera et al., 2010; Speijers et al., 2010). A higher proportion of cows hind feet that were affected by DD were cured by footbathing with a solution of acidified ionised copper twice a day for 47 days (20-24) compared to walking through a water footbath alone (12/23) (Manske et al., 2002). The efficacy of different copper sulphate concentrations has been recently investigated. Speijers et al., 2010 found that the mean transition grade (proportion of lesions that got better from one week to the next) and proportion of cows without DD at the end of a five week footbathing period was higher (0.36) for cows treated with 5% copper sulphate each week for four consecutive milkings compared to cows treated with 2% copper sulphate (0.13) or not footbathed (0.11). Similar results were found when the trial was repeated for 8 weeks and a fortnightly footbath was introduced. It was found that significantly more cows had no DD lesions (0.53 versus 0.36, respectively), and the mean transition grade of DD was higher when treated with 5% compared with 2% weekly copper sulphate footbaths for four consecutive milkings (0.52 versus 0.38, respectively) (Speijers et al., 2010). On the basis of this information the authors concluded that 5% copper sulphate can be used to control DD, but it did not prevent new or re-infected DD lesions from occurring (Speijers et al., 2010).

Blowey (2007) reported that farmers have begun to pump circulation cleaner from the milking parlour wash cycle directly into their footbaths, to use as a cheap and cost effective alternative solution. A clinical trial to assess the use of sodium hypochlorite and oxytetracycline found that the best combination of treatment which resulted in an 87% cure rate was a 1% sodium hypochlorite footbath administered twice a day for 30 days with four treatments of parenteral oxytetracycline (Silva et al., 2005). The next best cure rate was found where cows were only footbathed twice a day with 1% sodium hypochlorite which cured 73% of cases, compared to a cure in 57% of cases where cows were just given four treatments of parenteral oxytetracycline. Although the authors suggested that the use of systemic antibiotics should be considered given the highly contagious and complex nature of DD infections, this study suggests the isolated use of systemic antibiotics was not as effective at fighting the local infectious process compared to the isolated use of a topical bactericide (Silva et al., 2005).

In practice, treatment of DD is left to the farmer's discretion. The degree of veterinary or foot trimmer involvement may vary considerably from farm to farm. Management of DD will be influenced by the farmer's perception and awareness of the disease and attitude towards disease control. If advice is not sought or unavailable, farmers may develop farm specific interventions. Implementation of treatment can also be influenced by factors beyond the control of an individual farmer or vet (i.e. market supply of treatment), or subject to seasonal, time, labour or financial constraints. As such, management approaches employed on farm in practice, are likely to be far more varied than those reviewed in the research literature.

As a result this chapter describes a survey intended to determine the DD management practices actually being implemented by UK farmers. A telephone survey of ninety farmers was used to gather these data. The survey aimed to capture the 'breadth and depth' of existing treatment actions, rather than engaging the farmers' opinions on an optimal management strategy. Farmers and herdsmen from farms infected with DD and representing the main UK dairying counties were recruited at Dairy livestock shows or through the telephone directory. A telephone survey was then conducted to gather information about their approach to DD control and treatment. Specific areas of interest were:

1) **perception** - whether farmers perceived DD to be a problem and how they ranked the implications of the disease for the cows/to their business,
2) **management** - who had responsibility for managing DD, how was it normally treated and whether and how the treatment strategy changed,
3) **individual treatment** - the frequency and range of treatments used by farmers to detect treat and monitor individual cases,
4) **herd treatment** - the frequency and range of herd level treatments employed by farmers to prevent and or treat the disease,
5) **control measures** - the frequency and range of prevention strategies farmers employed in an attempt to reduce the risk of DD outbreaks and transmission throughout the herd.

The study was intended to capture the farmers' views which underpinned their management strategy towards the disease, since attitudes serve to guide behaviour (Armitage and Christian, 2003).

5.2 Method

5.2.1 Farmer recruitment

Ninety farmers/herdsmen were surveyed over the telephone between 17th November 2008 and 19th January 2009. Fifty one farmers were recruited at two major livestock shows in the autumn of 2008 (the Annual Dairy Event and livestock show, Stoneleigh Park, Warwickshire and The South West Dairy Show, Bath and West Showground, Somerset). Farmers were approached and asked if they were willing to be contacted to discuss their management strategies for DD. Those that agreed supplied their contact information and were informed that they would be contacted by telephone during the following winter housing period. The criteria for inclusion in the survey were that the farmer worked on a dairy farm in the UK and reported currently having DD in that herd.

The remaining thirty nine farmers were recruited from the telephone directory. In an attempt to recruit a representative sample of the UK population, at least four farms from each dairy producing county were recruited throughout the south, midlands and north of England, and throughout Wales. Farmers were surveyed from the South West (22), the South East (20), the Midlands (10) and the North East (10) and North West (10) of the UK and Wales (18).

5.2.2 Survey protocol

Farms were telephoned and the researcher asked to talk to the member of staff who was responsible for treating the cows on a daily basis. The person answering the questions will be referred to as 'the farmer'. Telephone calls were made at the times in the working day when farmers would be most available to talk: after morning milking, over lunchtime and after evening milking. In some cases a convenient time to call back was agreed and then followed up by the researcher (JES). Farmers recruited via the telephone directory were introduced to the study in order to build rapport with the interviewer. Participants were informed that the survey would take between five to ten minutes to complete, all information would remain anonymous and they could decline answering any questions or withdraw at any point. Basic herd information was collected, including average herd size, number of members of staff, housing type and cow breed.

The survey started with questions relating to the farmers' perception of DD on their farm. Farmers were asked how they thought DD was introduced into the herd, whether they perceived DD to be a problem and why ("What are the implications for you and the cows?") and to rate their problem on a scale of minor, moderate or major. Farmers were asked how many cases they had had in the past year and how many cows were infected with DD on that day. Farmers were asked to include any additional comments relevant to their perception of DD.

Farmers were then asked questions relating to detection and treatment of DD: who works with the cows and would normally detect and treat lesions, how would they normally treat a case and would this ever change and under what circumstances? If farmers said they treated cases individually, they were asked what method they used to detect the disease ("How do you notice a cow with a lesion?"), where they detected DD, e.g. in the parlour, and what lesions looked like when they were first seen, and how they progressed. Next they were asked how long after detection it would be before a cow was treated, how and where they would normally treat a case, whether they re-examined/re-treated cases, whether they separated a case from the rest of the herd and if so why. Finally, farmers were asked if they ever used parenteral antibiotics for the treatment of DD, if so what type and whether they thought this was effective. Farmers were invited to include any additional comments relevant to their detection and treatment of individual cases.

If farmers said they used a footbath to treat the whole herd, they were asked when and how often they footbathed, whether this was a routine or in response to a flare up/problem, what solutions and concentration they used, whether this ever changed and why, how many cows walk through the footbath, which cows walk through the footbath, whether feet are cleaned off before they walk through and how effective they found their footbath. Farmers were asked to add any additional comments which would further explain their herd level treatment strategies.

Farmers were asked whether they had put any routine prevention measures in place to reduce the risk of DD and if so what they were and why. Finally they were asked if they would like to add any other comments relating to control measures for DD.

5.2.3 Survey design

The survey was designed to engage farmers in a way that would find out how they actually managed DD on farm, rather than eliciting their opinion on an ideal management strategy. An open ended questioning approach was adopted, in an effort to provide as much opportunity for comprehensive answers as possible without leading the farmer in a particular direction. At the end of each sub-section, farmers were asked to contribute any comments which would further explain their attitude towards disease control and how this impacted on their management decisions. Prior to the start of the study, an initial phone survey was constructed and piloted with four local farmers to practise the timing of questions, and amend the flow and order of subject matter. To increase the likelihood of compliance, the survey was designed and practised to ensure it took no longer than ten minutes to complete.

5.2.4 Data analysis

Raw data were entered into an Access Database then transferred into Microsoft Office Excel 2007 for analysis. Descriptive statistics were produced for farmers' responses to each question. Responses were grouped into categories, counted and percentage scores for each response category were calculated. The median, standard deviation, and range were calculated for the farmer estimates of prevalence and incidence of DD, herd size and number of cows sent through the footbath as these parameters were not normally distributed. Farmers' expanded comments on the decisions they took to manage DD were analysed separately using discourse analysis. Comments were analysed under the categories: perception of DD, individual interventions, herd interventions, and prevention measures. The most commonly reported themes were clustered and led to seven conclusions. Quotes from farmer are used to illustrate each conclusion.

5.3 Results

5.3.1 Response rate

Sixty five farmers were recruited at two major livestock shows in the autumn of 2008 by JES, of which fifty one farmers were successfully surveyed (78%). Twelve percent were not surveyed due to being unable to get hold of them over the telephone. Fifty five farmers were contacted from the telephone directory, of which thirty nine farmers were surveyed. The telephone response rate was therefore 71%. Reasons why farmers were not able to carry out the survey were there was no one available for questioning at the time of the call and were too busy generally to take part or they had recently sold their dairy herd. All farms were eligible to take part as all reported having DD.

5.3.2 Farm demographics

Eighty two farm owners (91%), four farm managers (4.5%) and four herdsmen (4.5%) participated in the survey, of which sixty two farms had Holstein Friesian (69%), and twenty eight farms had Friesian, Jersey, Guernsey, Brown Swiss, Norwegian Red or Ayrshire (31%) breeds. Seventy farms had cubicle housing (77%), four had straw yard housing only (5%) and sixteen farms had a mixture of both (18%). The herd size ranged from 50-1100 cows (median 200 ±175).

5.3.3 Farmers' perception of digital dermatitis

Sixty eight (76%) farmers viewed DD to be a problem overall. When asked how to rate the disease, forty one farmers (46%) described DD as a 'minor' problem, 39 farmers (43%) described it as a 'moderate' problem, but only 10 farmers (11%) described it as a 'major' problem. The prevalence of DD reported by farmers on the day of survey ranged from 1 to 90 cases (median 6 ±17). The number of DD cases reported per year ranged from 2-300 (median 25 ±51). The incidence was 19 cases per 100 cows per year.

Sixty two farmers (69%) expressed an opinion about how DD was introduced onto their farm, the results of which are summarised in Figure 5.1. The most commonly reported route of transfer was through bought in cattle (62%).

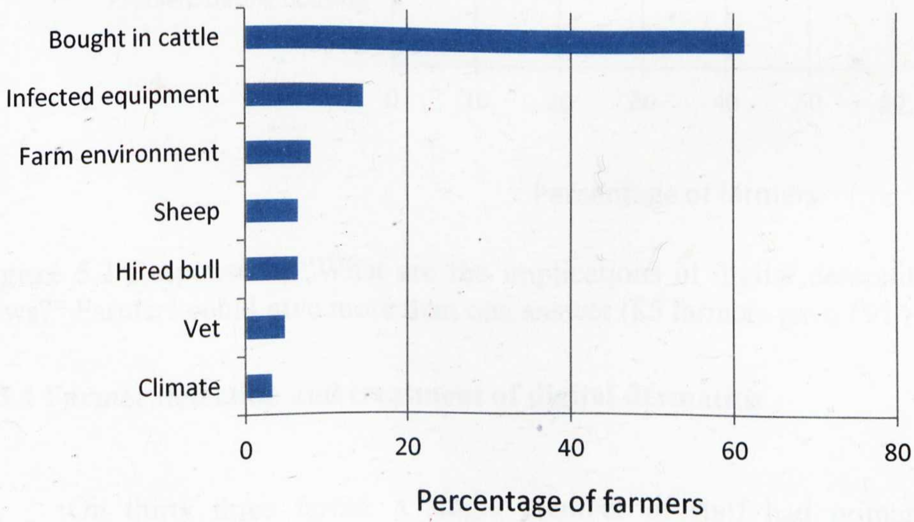


Figure 5.1 Response to "How do you think digital dermatitis was introduced into your farm?" Farmers could give more than one answer (62 farmers gave 65 responses).

Eighty five farmers (94%) reported what they believed to be the implications of DD, the results of which are summarised in Figure 5.2. Lameness (53%), milk yield (39%) and pain (36%) were the most commonly reported implications.

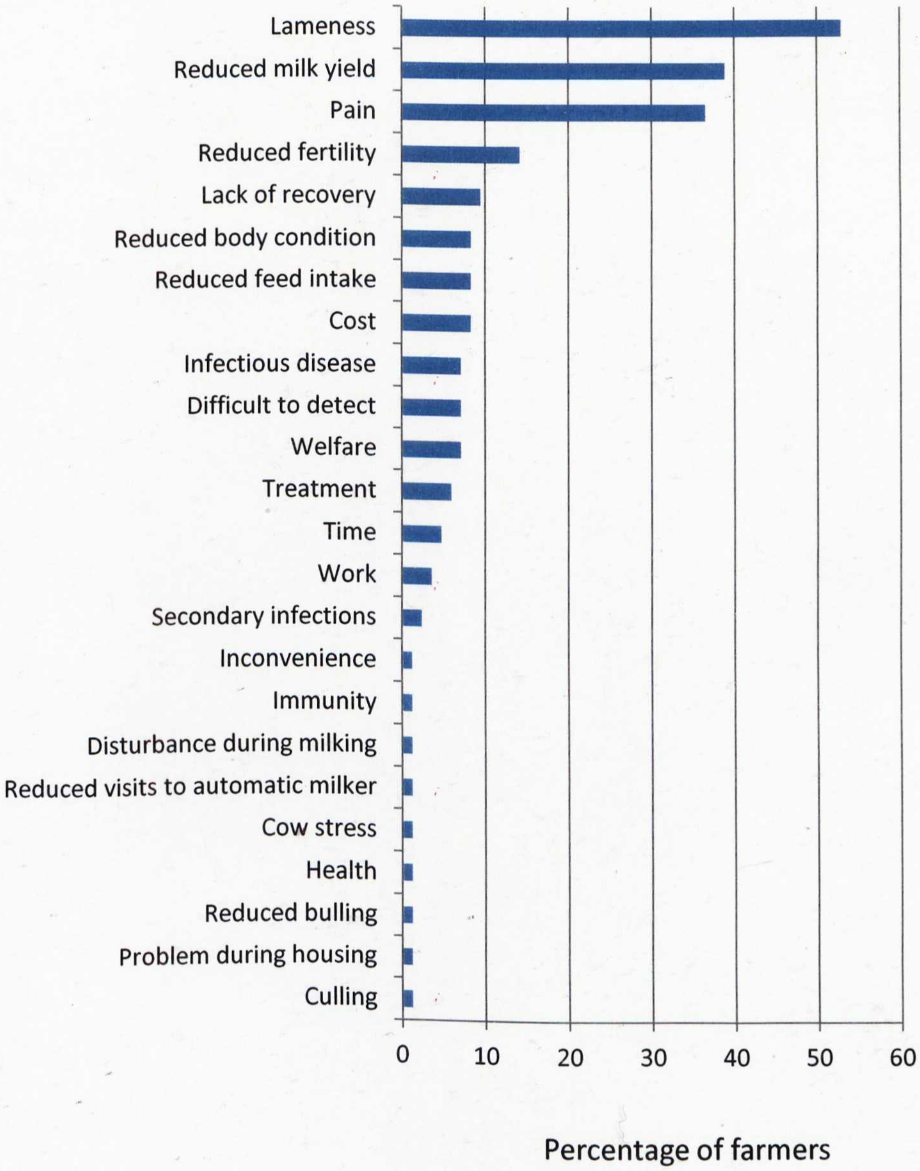


Figure 5.2 Response to "What are the implications of digital dermatitis for you and your cows?" Farmers could give more than one answer (85 farmers gave 191 responses).

5.3.4 Farmer detection and treatment of digital dermatitis

On thirty three farms, a single member of staff had primary responsibility for detection and treatment of DD (37%). On forty five farms (50%) two members of staff shared responsibility. Eleven farms (10%) had three members of staff and one farm (1%) had four members of farm staff responsible for DD detection and treatment. Of these, with this responsibility ninety five (61%) were farm owners, 36 (23%) were herdsmen, ten (6%) were farm hands, eight (5%) were foot trimmers and four (3%) were farm managers, one (1%) was a vet, and one (1%) was a relief milker.

Figure 5.3 summarises the range of treatment interventions farmers employed to deliver DD treatment to their cows. Only four percent of farms did not administer any individual treatment. Fifty six percent of farms used herd footbathing and would treat any individual case they identified. Twenty one percent of farms footbathed and would only treat individual cases that were severe. The remaining nineteen percent of farmers used individual treatment with no herd level footbathing intervention.

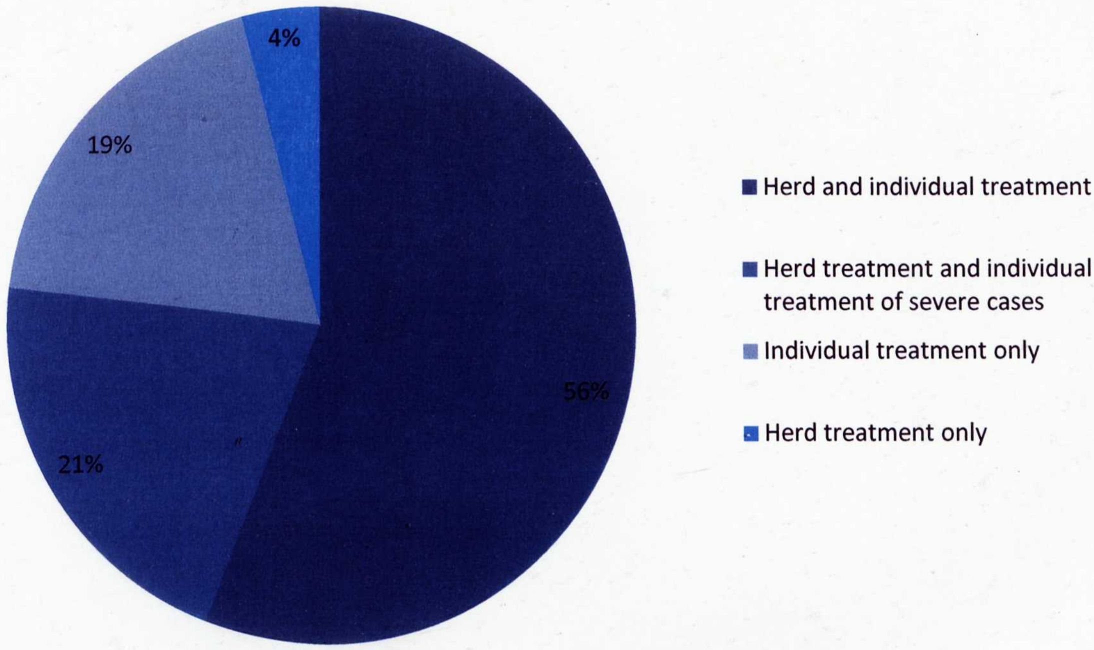


Figure 5.3 Response to "How do you normally treat cows for digital dermatitis?" (n=90).

Fifty seven (63%) farmers reported their normal method of treating DD had changed during the past year. The most commonly reported reason for this was in response to a flare up (44 farmers, 49%). Other reasons for changing strategy were due to: advice from their vet, foot solution agent or foot trimmer (3 farmers, 3%), the onset of the winter housing period (2 farmers, 2%), formalin irritating cows feet (2 farmers, 2%), more than five individual cases of DD at any one time (2 farmers, 2%), harvesting and holiday interrupting the treatment regime (1 farmer, 1%), a new parlour set up (1 farmer, 1%), an easier method of treatment (1 farmer, 1%), a change of herdsman (1 farmer, 1%), and the need to use a different solution to harden the feet (1 farmer, 1%).

Figure 5.4 illustrates how farmers change treatment strategy during the year. Footbathing more often (33%), starting footbathing (31%), and changing footbathing solution (22%) were the most commonly reported changes.

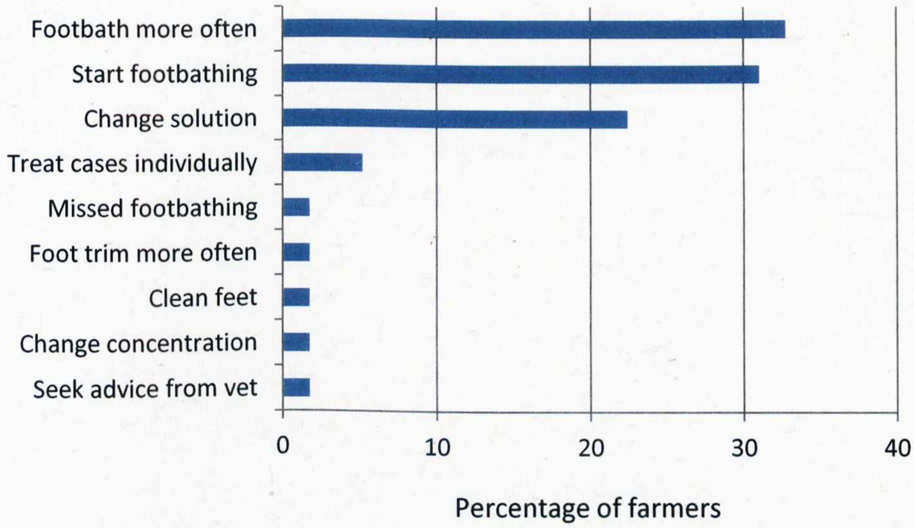


Figure 5.4 Response to "How does your normal method of treating cows change throughout the year?" (n = 58).

5.3.5 Individual treatment strategies

Table 5.5 summarises the ways in which farmers detect DD. Lameness (50%), seeing the lesion (40%), lifting or resting the affected limb (21%), tenderness (18%) and smell (17%) were the most commonly reported methods.

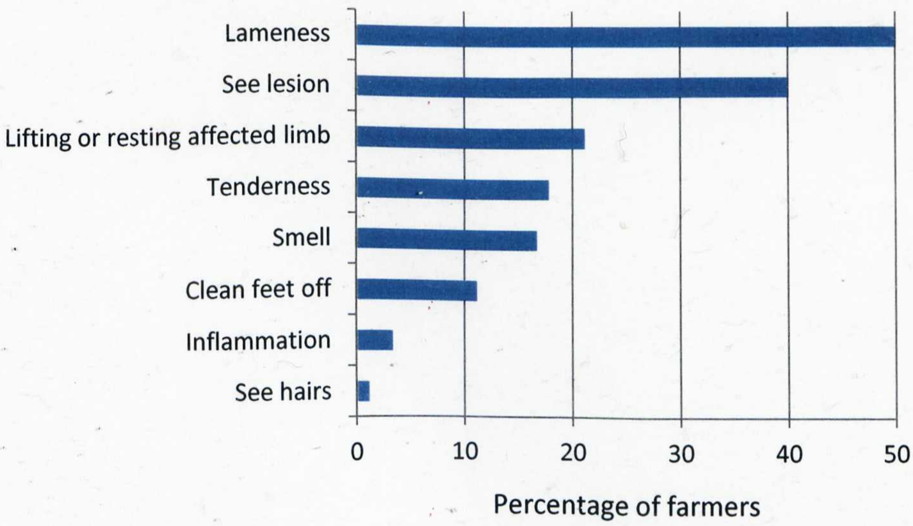


Figure 5.5 Response to "How do you notice a cow with a digital dermatitis lesion?" Farmers could give more than one answer. (90 farmers gave 145 responses).

Eighty two percent of farmers reported normally detecting DD in the parlour, thirteen percent everywhere, seven percent on the yard, four percent in the crush and two percent in the housing. Five farmers (6%) were aware that their description of digital dermatitis would depend on the stage at which they detected a lesion. Figure 5.6 summarises how farmers describe DD lesions when they first detect them. Lesions were most commonly described as red (30%) and 0.5 inches in diameter (22%).

Eighty six farmers (96%) reported treating cases at an individual level, of which fifty five farmers (64%) reported treating a lesion at the time of detection. Seventeen farmers (20%) described treating a lesion the day after detection. Four farmers (5%) reported treating a lesion within one to two days of detection and seven farmers (8%) reported treating a lesion within a week of detection. However, three farmers (3%) reported leaving treatment to the foot trimmer up to a month later. Farmers reported treating lesions in the crush (39%), in the parlour with follow up treatment in the crush (32%), in the parlour only (25%), in the crush initially with repeated treatment in the parlour (3%) and at the feed rail (1%).

Figure 5.6 illustrates the ways in which farmers described DD lesions when they first detect them. The most common description in 52% of cases were small (0.5 inch) red lesions characteristic of the early erosive stage of disease development.

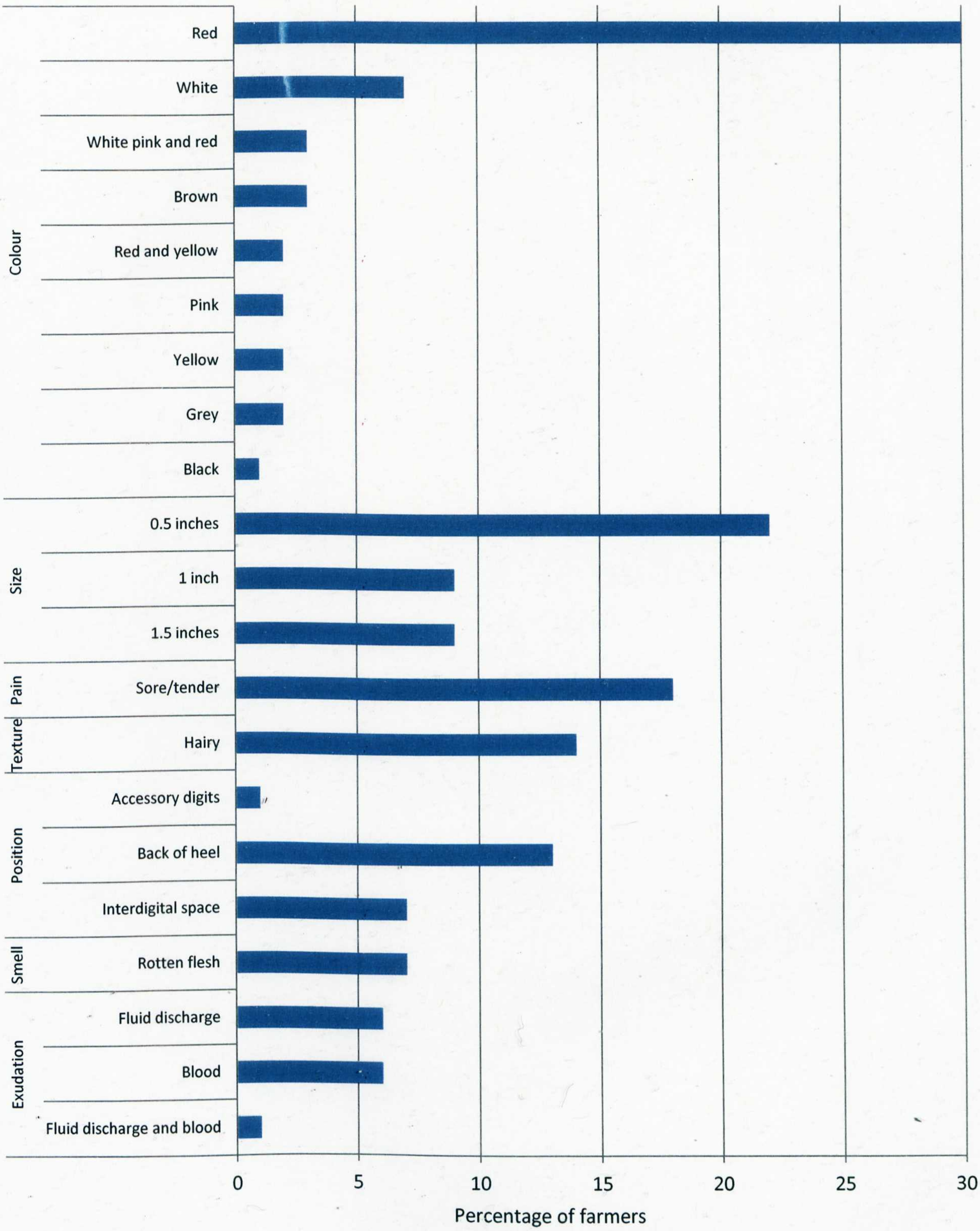


Figure 5.6 Response to "What do lesions look like when you first detect them?" Farmers could give more than one description in any category. Ninety farmers gave 141 responses.

5.3.5.1 Types of individual treatment

The most commonly used topical treatment for DD were oxytetracycline (60%); lincospectin powder (22%) and copper sulphate powder (17%). In addition to the treatment preparations described below (Figure 5.7), twenty six farmers (29%) report bandaging all lesions; eighteen (20%) bandage severe lesions and forty six (51%) did not bandage lesions.

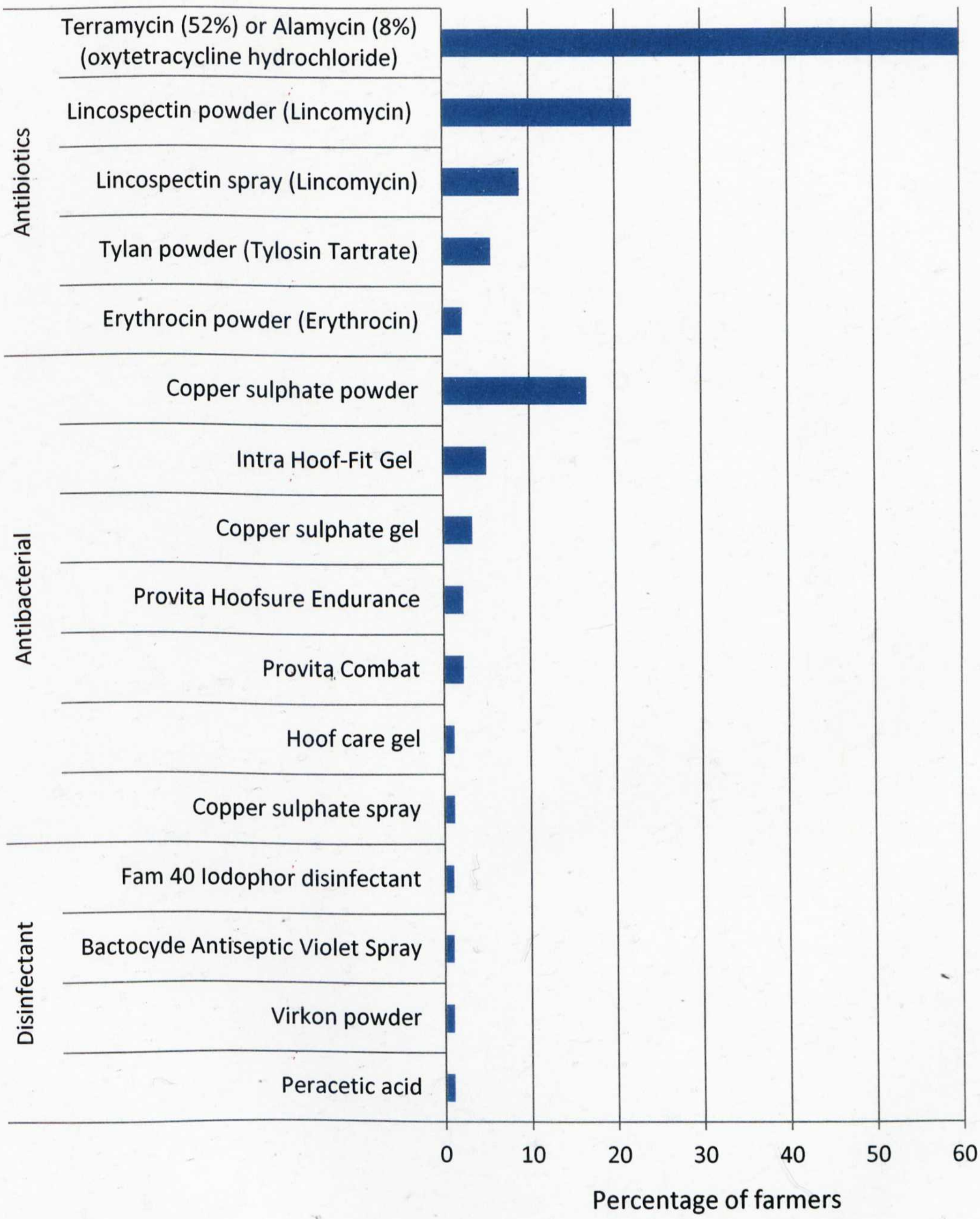


Figure 5.7 Response to "What individual treatments do you use?" Farmers could report more than one treatment type. Eighty six farmers gave 124 responses.

5.3.5.2 Duration of individual treatment

Seventy (78%) farmers described re-examining all lesions, eight (9%) report re-examine severe cases only and twelve (13%) do not re-examine lesions. Table 5.8 summarises the number of times farmers report re-examining cows after initial treatment. Twenty one farmers (23%) reported separating a cow with DD from the rest of the milking herd in the event it caused severe lameness.

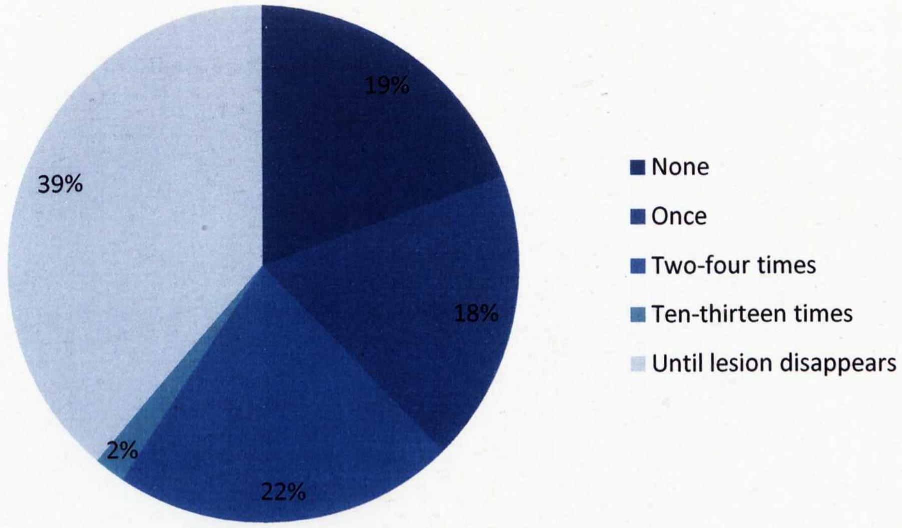


Figure 5.8 Response to "How many times do you re examine or retreat an individual case of digital dermatitis?" (n=86).

5.3.5.3 Systemic antibiotic treatment

Forty six farmers (51%) reported using systemic antibiotics to treat DD, of which, seventeen farmers (19%) use them for severe cases only. Ninety six percent of the farmers who use systemic antibiotics reported it to be effective. Two farmers (4%) described systemic antibiotics as more effective in conjunction with topical antibiotic spray. The range of systemic antibiotics used by farmers are summarised in Figure 5.9. The most commonly reported antibiotics used were Excenel (Ceftiofur, Pfizer Limited) (43%) and Tylan (Tylosin phosphate, Elanco Animal Health) (32%). Farmers described using systemic antibiotics in severe cases (24%), in conjunction with secondary infections (20%), in all cases (3%), for first cases in heifers (2%) and at drying off (1%).

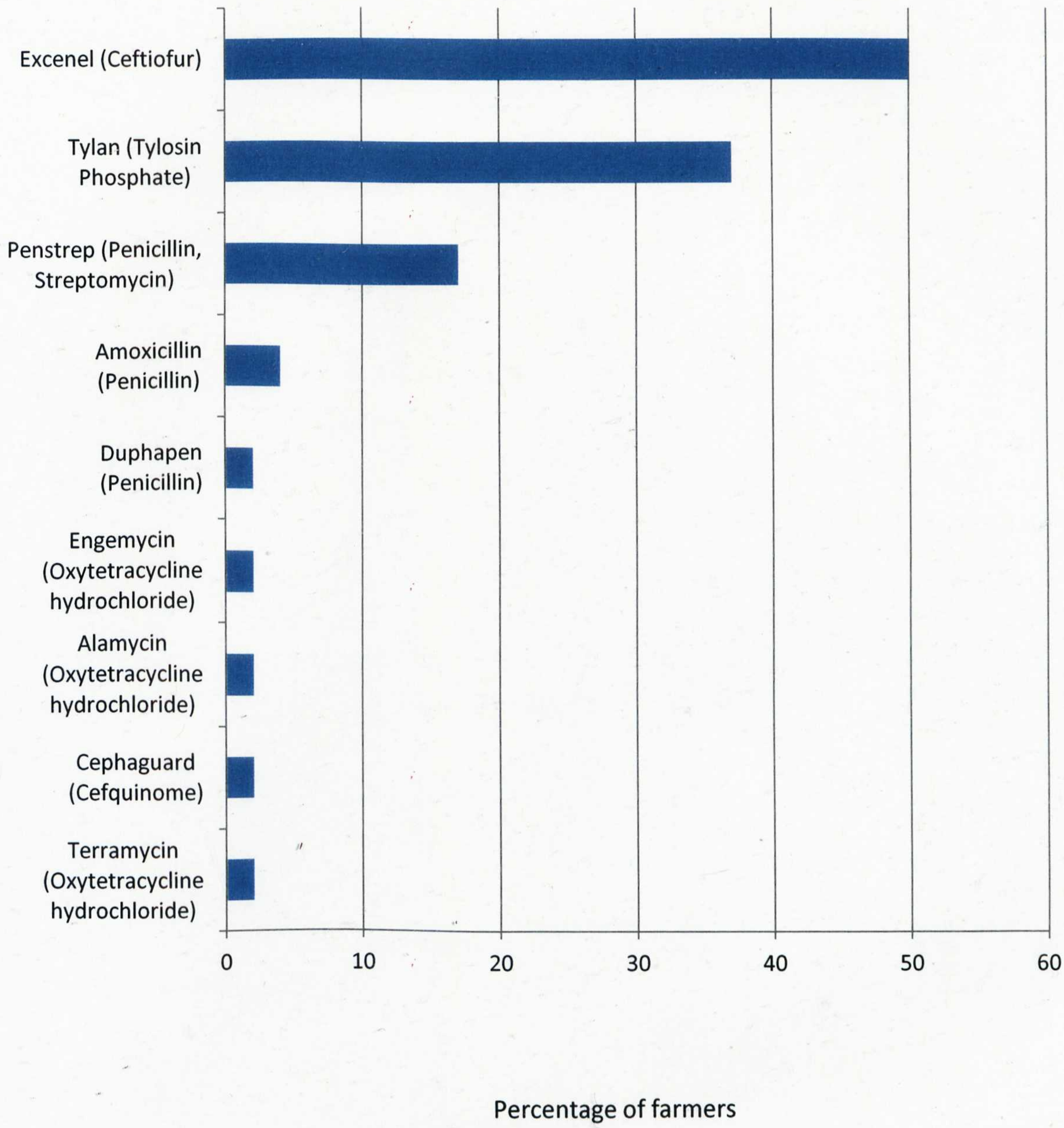


Figure 5.9 Response to "Do you use injectable antibiotics for the treatment of digital dermatitis? If so, what?" Farmers could report more than one injectable antibiotic. Forty six farmers gave fifty six responses.

5.3.6 Herd treatment strategies

Seventy three farmers (81%) reported using footbathing to prevent or treat DD. Fifty farmers (68%) reported footbathing throughout the year and twenty three farmers (32%) reported footbathing during the housing period only. Fifty eight farmers (79%) described footbathing as a routine, seven farmers (10%) footbathed only in response to a flare up, and eight farmers (11%) footbathed routinely as well as in response to a flare up. Figure 5.10 illustrates that the frequency of footbathing varies considerably from farm to farm. The most commonly reported frequencies of footbathing was twice a week (23%), followed by once a week (18%), four times a week (11%) and once a fortnight (10%).

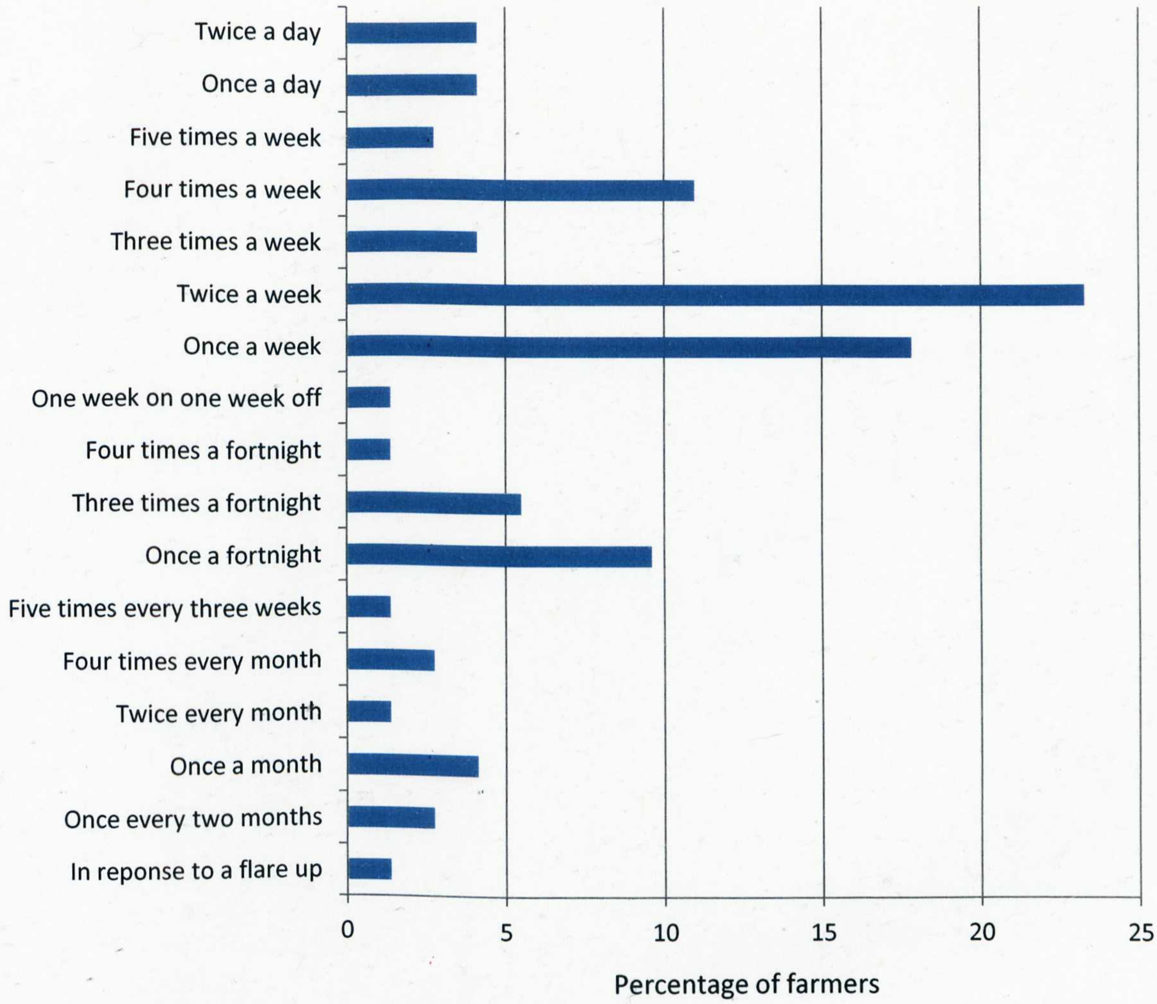


Figure 5.10 Response to "How often do you footbath the whole herd?" (n=73).

Figure 5.11 illustrates the footbathing solutions used by farmers. The most commonly reported solutions were formalin (55%), copper sulphate (33%) and lincospectin (21%). Fifty farmers (68%) were able to report the solution concentration for formalin or copper sulphate: thirty six (72%) reported using five percent concentration, seven (14%) use a ten percent concentration, four (8%) use a three percent concentration, two (4%) used a two percent concentration and one (2%) used a seven percent concentration.

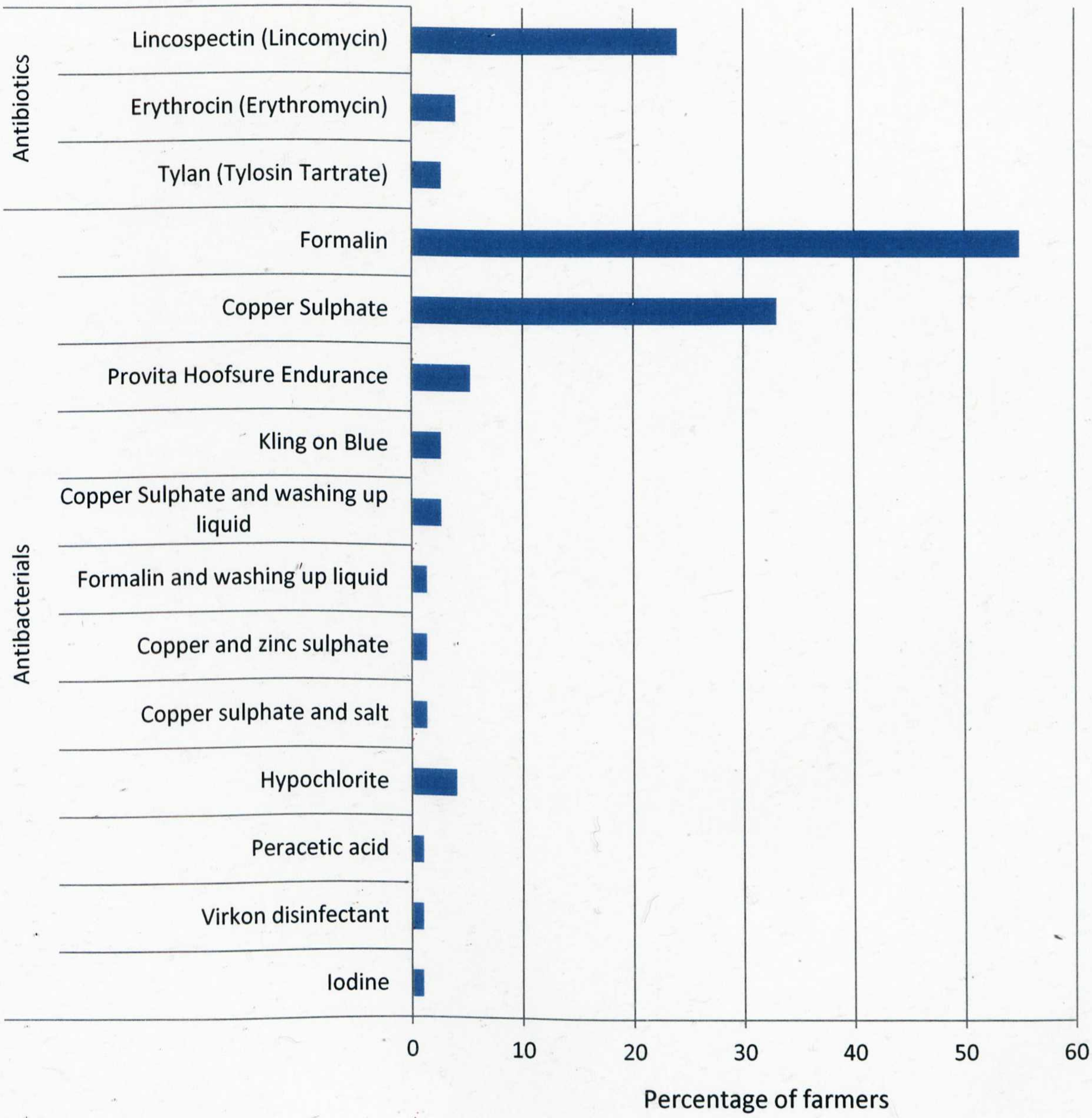


Figure 5.11 Response to "What solution(s) do you use?" Farmers could report more than one footbathing solution. Seventy three farmers gave 103 responses.

Less than 100 cows (22%), 101-200 cows (42%) and 201-300 cows (23%) were the most commonly reported number sent through the footbath before the solution was changed. Groups of 301-400 (10%), 401-500 (7%), and 601-700 (1%) were also reported.

Fifteen farmers (21%) reported footbathing their dry cows, and three farmers (4%) footbathed their heifers. Twenty (27%) farmers reported not cleaning their cows' feet off before entering the footbath, forty two farmers (58%) clean all cows' feet off, ten farmers (14%) cleaned dirty feet only, and four farmers (5%) cleaned DD cases. Thirty four farmers (47%) reported hosing down cows' feet in the milking parlour, twenty (27%) used a prewash footbath and four (5%) used both a hose and a prewash footbath. Seventy one (97%) farmers that footbath consider it to be an effective control measure.

5.3.7 Prevention and control measures for digital dermatitis

Eighty nine farmers (99%) reported putting one or more routine prevention measures in place to reduce the prevalence of DD in their herd (Figure 5.12). Foot hygiene (57%), footbathing (49%), foot trimming (21%), keeping a closed herd (15%) and bedding hygiene (19%) were the most commonly reported preventions.

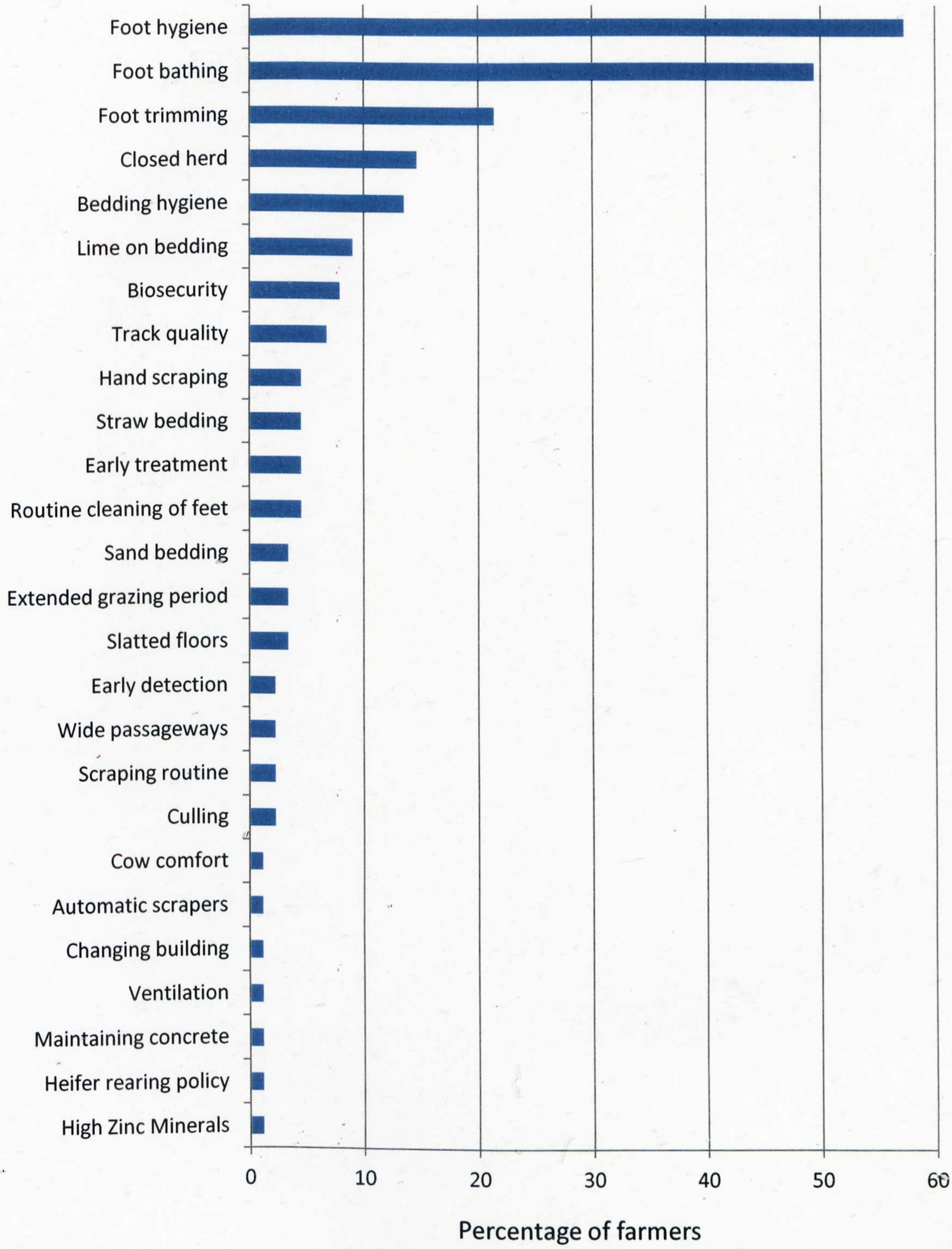


Figure 5.12 Response to "Do you use any routine prevention measures for digital dermatitis? If so, what are they?" Farmers could report more than one prevention strategy. Eighty nine farmers gave 200 responses.

5.3.8 Discourse analysis

At the end of each subsection, the interviewer asked the farmers if they would like to add any further comments which may further explain their management decisions for DD. This was intended to capture views which underpin their perception, treatment and prevention approaches to the disease. Comments on perception of DD (62% of farmers), individual treatment interventions (70%), herd treatment (89%), and prevention measures (89%) were collated, and the seven most common themes with the following conclusions emerged:

1. **Digital dermatitis has an inconsistent effect on lameness and is therefore difficult to detect.**

Twenty one percent of farmers suggested that cows with DD did not always display obvious or consistent signs of lameness. Several farmers said:

> "Only 30% of cows with DD are lame"
>
> "Cows with DD walk normally and then bow over as if they have just stepped on a nail"
>
> "It doesn't bother some cows and others act like their legs [are] about to fall off"

Associated with their observation that DD doesn't cause lameness; farmers thought that DD was difficult to detect. Several farmers stated:

> "If you know of 12 cases today, you should assume there are another 12 cases you can't see until the lesion develops".
>
> "You will get 10-15% of the herd with obvious clinical cases that I [the farmer] can detect due to lameness but 50-60% of the herd look tender on their feet which I also attribute to DD"

2. **Digital dermatitis is a consequence of buying in stock**

Twenty three percent of farmers suggested that buying in stock had introduced DD into their herd. For example:

> "We have bought in this problem due to cow expansion"
>
> "Up to two years ago this herd was closed. We had to buy in stock and we've had a problem with DD ever since"
>
> "We never used to have a problem but DD has spread through the whole herd after introducing new cows from elsewhere"

Of these, five percent of farmers felt that the introduction of DD was linked to the culling of livestock due to tuberculosis:

> "We had to get new cows from a farm sale four years ago after a bad spell of TB. Before this the herd was closed. We have just bought DD in because of TB"
>
> "We now have 10% lame cows every year due to DD from bought in stock. It's a symptom of TB"

3. **Continuous footbathing is essential to prevent DD but it does not eradicate the disease.**

Twenty five percent of farmers felt that in order to control DD it was necessary to routinely footbath the whole herd:

> "If you stopped footbathing half the herd would have DD. You have to keep footbathing all the time"
>
> "We get 10-15% of the herd affected each year but if we didn't footbath it would be more like 70%"
>
> "If you don't keep on top of DD with footbathing, you have to treat more individually in the crush"
> "Once you start, you can't stop"

Although farmers felt continuous footbathing is essential to control DD, thirty five percent of farmers did not believe footbathing can eradicate the problem:

> "Footbathing only contains DD. It does not eradicate it"
>
> "Footbathing is a prevention measure only. It does not penetrate chronic cases"

4. **Individual treatment is more effective than footbathing.**

Forty six percent of farmers deemed individual treatment far more effective than treating at a herd level. Several farmers said:

> "Footbathing disinfects feet, it's not a treatment. Once you individually treat a cow, DD clears up straight away"
>
> "Individual treatment is far more effective than treating cows at a herd level"

5. **Systemic antibiotics are an effective treatment for DD, particularly in chronic cases.**

Thirty seven farmers advocated the use of systemic antibiotics for the treatment of DD. A few examples of this were:

> "Systemic antibiotics are very effective for the treatment of DD. It is excellent on mild or severe cases"
>
> "When DD is associated with swelling, injectable antibiotics are useful and effective"
>
> "Tylan is effective on severe cases in combination with topical antibiotic treatment"

6. **In order to control DD, a regular and efficient scraping routine is required.**

Forty one percent of farmers concluded that routine scraping was essential as a prevention measure for DD. For example:

> "You have to keep your yards clean with regular scraping and always use the hand scraper to clear the stale muck from the corners"
>
> "Clear the stagnant muck lying in corners as this is where the bugs are"
>
> "We have wide passageways to reduce the build up and contact cows' feet have with slurry. You have to keep feet clean and dry with regular slurry management"
>
> "Keeping a clear and tidy farm makes scraping easy"

7. There is a lack of knowledge and best practice advice for treating DD

Eighteen percent of farmers felt that there was a lack of best practice knowledge and advice for the treatment of DD. For example, several farmers said:

> "There are so many products on the market which all say they work but how do you know?"
>
> "The vet sold me some drugs to use in the footbath but the problem got worse. Individual treatment works much better"
>
> "Our vet told us injectable antibiotics don't work but other farmers use it"
>
> "Our preventative routine works well but I would be keen to find a product that would treat DD at a herd level that only needs to be used once a week"
>
> "I'm not happy with the recommended solutions; they are expensive and not good for our health or effective at treating the cows. Farmers are looking for a solution that works but that is cow and farmer friendly"

5.4 Discussion

The purpose of this questionnaire was to explore how farmers describe the management strategies they chose to adopt for detecting, treating and preventing DD. This questionnaire surveyed ninety dairy farms endemically infected with DD throughout England and Wales, employing one to four members of staff to manage between 50 and 1100 cows. However not all interviewees were responsible for treating cows. Ninety one percent of interviewees were farm owners/farmers, of which only sixty two percent were responsible for managing DD on a day to day basis. In an effort to capture present management practices, only farms that reported currently having DD were recruited.

The farmers' willingness and motivation to participate may bias the study towards a proactive sample. For example, no effort was made to re-contact potential participants who initially refused to participate on the phone. This additional effort is worthwhile if it results in a sample that is more representative of the target population. However this was not recorded as part of the present study. A further potential bias is geographic representation. The majority of farmers were recruited at two dairy events in the south west and midlands. In an effort to balance the geographical sample, farmers recruited via the telephone directory were selected from counties that were under represented by the dairy event recruitment. However, in order to recruit a representative sample of the population, a sample needs to reflect the number of dairy farms from each dairy producing country in relation to the proportion of the entire UK dairy herd they represent. Unless a representative sample is gained, it is more difficult to extend the conclusions of the study to the entire population.

In the present study farmers were asked to provide information about the prevalence and incidence of the disease. This prompted a self estimate rather than a review of records. Farmers estimated a median prevalence of six cases (ranging from one – ninety on the day of survey) and an incidence of nineteen cases, with twenty four and ten percent of farmers, respectively, unable to provide an answer to this question. Previous research has reported an average DD prevalence of 48% in heifers across sixty UK farms (Bell, 2003) indicating that farmers responding to the telephone survey may have underestimated the levels of DD in their herds. If farmers underestimate the disease prevalence, they will not perceive a problem and a need to take action to control it (Whay, 2002b). Despite the scale of the problem, only ten percent of farmers perceived DD to be a major problem. This agreed with the findings of Leach et al., (2010) who reported that 90% of farmers did not perceive lameness to be a major problem on their farm despite an average prevalence detected by researchers visiting the farm of 36%.

Forty percent of farmers claimed that buying in stock was responsible for introducing DD into their herd. A cross sectional study observing 3,265 cows across 22 farms throughout Chile identified that farms that had bought in heifers in the past ten years had a threefold increase in the likelihood of having DD compared to closed herds (Rodriguez-Lainz et al., 1999). Here discourse analysis revealed farmers discontent at buying in DD with new stock, often describing this as an imposed change to management partly as a by-product of culling cows with tuberculosis. However, when farmers were asked what actions they took to prevent DD entering the herd just fifteen percent reported a closed herd, and only eight percent identified the use of biosecurity.

Two of the most commonly reported impacts of DD were lameness (53%) and pain (36%) in the present study. When given a choice of words to describe the outcome of lameness Leach et al., (2010) found that farmers unanimously described the 'pain and suffering' caused by lameness as 'very' or 'extremely' important but that lameness was not the top priority for farmers in comparison to mastitis and fertility. In the present study, decreased milk yield was the second most commonly reported outcome (39%) after lameness, although cost as a specific issue was only mentioned in eight percent of cases. Esslemont et al., (2005) estimated the cost of a single case of DD to be between £75 and £82, however, as is the case here, previous research has found that many farmers fail to consider the economic impact of lameness (Leach et al., 2010).

When asked how they normally treat DD, seventy three percent of farmers footbathed and only four percent did not carry out any individual treatments. Farmers rely on footbathing because of its ease of application. However discourse analysis revealed that although farmers described footbathing as a necessary control measure, 46% of farmers believed that individual treatment was a more effective approach. Despite this, only nineteen percent of farmers declared treating DD solely on an individual basis. This dissociation may be explained by the impracticality of treating cows on an individual basis compared with herd level footbathing, particularly as disease prevalence and herd size increases.

Sixty four percent of farmers that footbath report changing strategy most commonly in response to a flare up. The most common treatment changes were footbathing more often (33%), starting to footbath (31%) and changing the footbath solution (22%). There were different levels of emphasis placed on the frequency of individual treatment amongst farmers who footbathed. Twenty one percent described treating only severe cases individually, where as fifty six percent reported treating any individual cases detected. This may reflect different attitudes towards their treatment approach.

Farmers also reported using a wide range of methods for detecting individual cases for treatment: lameness, seeing the lesion, lifting or resting the affected limb, tenderness, and smell. Furthermore, discourse analysis identified that 21% of farmers believed that DD had an inconsistent effect on locomotion making detection problematic. Findings from the previous chapter suggest that lifting of the hind feet is more consistently associated with DD than lameness and that 52% of cows with DD score 1B, a tender, slow footed gait and soft placement of feet, compared with 20% that were lame (score 2 or above). However half of the farmers surveyed reported using lameness as a means of detection, where as only eighteen percent reported using tenderness. It is therefore of concern that farmers are likely to prioritise treating lame cows first.

Of further concern is the finding that not all detection of DD translates into immediate treatment. Sixty one percent claimed to treat immediately at detection, however, three percent left individual treatment for up to a month. Only fifty two percent described detecting lesions at the early ulcerative stage: 30% described lesions as 'red' and 22% described lesions as 0.5 inches in diameter. Eighteen percent reported that lesions were as large as 1-1.5 inch in diameter at detection and 14% described lesions as 'hairy' at the point of detection. These are descriptions of granulomatous and proliferative lesions at the mid to later stage of progression. Best practice advice is for early treatment, to maximise recovery and minimise reoccurring cases.

Farmers reported using a wide range of topical solutions for individual treatment, with a third of farmers using more than one solution: ninety six percent report using antibiotics, thirty percent use antibacterials and only four percent use disinfectants. This may reflect the morbidity of the disease as in the vast majority of cases antibiotic treatment is administered. Sixty percent of farmers report using the licensed, recommended oxytetracycline spray. The other most commonly reported options were neat lincospectin powder or spray (26%) and copper sulphate powder (17%).

Eighty nine percent of farmers reported re-examining and re treating individual cases, between one (18%) to thirteen times (1%). This may reflect the disease state at first treatment. Vink (2006) recommended repeated treatment to avoid regular reoccurrences of the disease. Recent research has suggested that the median duration of lesions can be 42 days even with an aggressive regime of topical treatment lasting up to a week (Nielsen et al., 2009). If inadequately treated DD will become chronic persisting for months and regularly reoccurring (Somers et al., 2004).

Despite equivocal research evidence for their efficacy (Blowey and Sharp, 1988, Borgmann et al., 1996, Britt et al., 1996) the use of parenteral antibiotics is becoming increasingly common on farm as a DD treatment. Fifty one percent of farmers reported using a range of systemic antibiotics which is surprising considering the perceived lack of effectiveness within the veterinary literature, the cost involved and potential milk withdrawal. Discourse analysis further revealed that farmers advocate the use of systemic antibiotics for the treatment of DD. The most commonly used antibiotics were Excenel (Ceftiofur, Pfizer Limited) (50%) and Tylan (Tylosin Phosphate, Elanco Animal Health) (37%). Only two percent of farmers reported using Cephaguard (Cefquinome, Intervet Animal Health), the licensed injectable antibiotic treatment for DD in the UK. Although there has been little support for their use in the past, more recent research has advocated their use.

Rutter et al., (2001) reported a cure rate of 82% in 50 cows treated daily with cefquinome for three days compared to no cure rate in twenty two untreated cases. In the UK, Laven (2006) found a five day course of 1 mg/kg cefquinome to be more effective than a three day course of one mg/kg cefquinome or single injection of ten mg/kg erythromycin. However this treatment was at least as effective as two erythromycin footbaths. Silva et al., (2005) reported an 87% recovery rate when systemic oxytetracycline was administered for 4 days in conjunction with topical application of 1% sodium hypochlorite using a 30 day footbath. Further research is urgently required into the efficacy of systemic and/or topical antibiotic interventions. A longitudinal study following disease regression given different interventions would evaluate the effectiveness of commonly used on farm approaches.

The range in footbathing frequency suggests a large amount of trial and error on farm. Seventy three farmers (81%) surveyed report using footbathing, of which 68% footbathed throughout the year and 32% footbathed during the housing period only. The frequency of footbathing ranged from twice a day (4%) to once every two months (3%), where sixty seven percent of farmers footbath at least once a week. Twenty eight percent of farmers reported using concentrations above or below the recommended dosage of five percent formalin or copper sulphate. Forty one percent of farmer's footbathed more than the recommended 200 cows (Hartog et al., 2001) through one solution at any one time.

The most commonly reported footbath solutions used were formalin (55%), copper sulphate (33%) and lincospectin (24%). Antibiotic (Laven and Proven, 2000) and formalin footbath solutions (Holzhauer et al., 2008) have been reported to be effective in both reducing prevalence and controlling the disease. It is of interest to note that in the current study 21% of farmers report using lincospectin in the footbath despite its expense and licensing restrictions (Laven and Logue, 2006). The widespread use of antibiotics has implications for both human and animal health (Shearer and Hernandez, 2000). There are environmental and human health hazards associated with disposal of copper sulphate with copper accumulation in the soil (Salam and El-Fabel, 2008). Copper sulphate has been found to be efficacious in reducing the prevalence of DD at concentrations of 2 to 10% (Teixiera et al., 2010; Speilers et al., 2010), although previous authors suggested it was not effective in all cases (Blowey and Sharp, 1988, Nutter and Moffitt, 1990, Rodriguez-Lainz et al., 1996).

This survey also found that treatment interventions were directed towards the milking herd with only 21% of farmers' footbathing dry cows, and four percent footbathing heifers. This identifies the need for advocating a farm wide intervention approach in order to reduce transfer of disease between groups.

Ninety one percent of farmers described using control measures to reduce the risk of DD, with interventions at a cow, herd and farm level. A total of twenty six control measures were reported, the top three concentrated on foot health: footbathing (57%), foot hygiene (49%), and foot trimming (21%). Discourse analysis further revealed that 41% of farmers who prioritised foot hygiene considered the scraping routine to be the most important control measure. A recent study suggests that farmers are investing their attention in appropriate areas. The most significant on farm risks for lameness were standing in wet slurry, factors that cause claw trauma; poor claw condition and inadequate foot care (Bell et al., 2008).

The farmer based treatment strategies derived from this survey were summarised, grouped and formed the selection criteria for the subpopulation of herds recruited for a longitudinal farm based study. This longitudinal observational study comparing the prevalence and severity of DD in a sub-set of farms employing a) individual cow treatment only and b) whole herd footbathing with additional individual treatment is described in chapter 6.

5.5 Conclusion

It is apparent that farmers are investing in a variety of intervention strategies in an attempt to reduce the prevalence of DD in their dairy herd. However few farmers perceived the disease as a major problem. At the same time, eighteen percent of farmers are dissatisfied with the current knowledge of the disease and the treatment options available. Digital dermatitis is a considerable welfare issue. The under-perceived importance of DD and the multitude of control approaches are causes for concern. Clear recommendations on practical and effective control measures are urgently required. In order to test intervention strategies, furthering our knowledge of the biology of the disease is essential. Longitudinal on farm intervention studies should continue to inform the dissemination of best practice advice.

Chapter 6

A longitudinal study comparing the prevalence and severity of digital dermatitis associated with two common management approaches

6.1 Introduction

Results from the farmer survey (chapter 5) indicated that the most commonly practised management strategies for DD consisted of either individual topical treatment only (19%) or a walk through footbath in conjunction with individual topical treatment of chronic cases (77%). The most commonly reported solutions used by farmers were formalin (53%) and copper sulphate (33%). Only four percent of farmers reported using footbathing without any form of individual treatment intervention at all.

Individual topical treatment is considered best practice for treating DD as it specifically targets the lesion site (Britt et al., 1993; Manske et al., 2002). However, in the UK, mass treatment of DD by footbathing is commonly used; eighty one percent of farms using footbaths in a recent survey (Chapter 5). Digital dermatitis is widespread in the UK and footbaths when utilized effectively may help to limit infection pressure. Such group level treatment strategies are attractive to farmers, particularly as herd sizes increase and when considerable proportions of herds become affected during severe outbreaks. In addition, the perceived cost and time associated with identifying and treating affected cows individually, often several times, motivates farmers to adopt herd level treatment approaches.

Despite the widespread use of many different footbathing solutions, there is a lack of information about efficacy and comparative data, resulting in a very variable and somewhat anecdotal approach to footbath use on farm. It appears that regardless of the method used, herd level treatment efficacy can vary considerably and recurrence of the disease is high (Berry et al., 1996; Read et al., 1998). Conversely the effectiveness of individual antibiotic treatment is well reported. Numerous studies have described the success of a single topical treatment of a lesion (Britt et al., 1993). Specifically, Manske et al., (2002) found that a single oxytetracycline application cured eighty seven percent of lesions, significantly more than the therapeutic effect of hoof trimming alone (thirty four percent of lesions). Other antibiotic treatments that have been recommended for use include erythromycin and lincomycin, both for topical application and as footbathing solutions (Blowey et al., 1994; Blowey et al., 1996).

A recent study comparing the topical effectiveness of lincomycin and oxytetracycline found no difference in cure rate. Seventy three percent of all treated cases were healed fourteen days after two treatments on day one and two (Berry et al., 2010). Anatomical location of lesions has been found to have an effect on the efficacy of topical treatment. Cows with lesions on the interdigital cleft are less likely to respond to treatment, compared to cows with lesions on the heels or the dewclaw (Hernandez et al., 2000).

Antibiotic solutions are not perceived as an ethical or sustainable option for routine treatment of DD due to legislative restrictions, expense to farmers and a concern of antibiotic resistance. Antibiotics should not be used to compensate for unhygienic underfoot housing conditions (Nuss, 2006). With the advent of organic farming, the use of non-antibiotic footbathing has become widespread (Laven and Logue, 2006). Anti-bacterial formulations such as formalin and copper sulphate are a more attractive prevention option as they can be used frequently at a lower cost.

Few controlled studies report an effect of footbathing several times a week. Several studies have reported formalin to be efficacious at five percent when used daily, in both reducing the prevalence of DD and preventing the disease (Holzhauer et al., 2008). Copper sulphate has been found to be efficacious in reducing the prevalence of DD at concentrations of between two and ten percent when administered daily (Teixiera et al., 2010; Speijers et al., 2010), although previous authors have suggested it is not effective in all cases (Blowey and Sharp, 1988, Nutter and Moffitt, 1990, Rodriguez-Lainz et al., 1996). More recently, one study reported the risk of DD to be reduced by 1.36 times in cows footbathed twice weekly with copper sulphate at ten percent compared to formalin at five percent (Teixeira et al., 2010).

Footbathing with copper sulphate twice daily for six months cured significantly more digital dermatitis lesions (20/24) compared to footbathing with water alone (12/23, Manske et al., 2002). However the study concluded that copper sulphate had no significant preventative effect on healthy feet. In contradiction to previous reports that lesions do not heal spontaneously and to the high recurrence risk (Berry et al., 1999), Manske et al.., 2002 found that despite treatment intervention, seventy five percent of all feet affected by DD cured during the grazing period.

Identifying both practical and effective interventions is a prerequisite for the control of DD on farm. The study described here aimed to examine the longitudinal impact of the two commonly reported treatment interventions employed by farmers. The two interventions were employing individual cow treatment only, or using a herd level footbathing regime (copper sulphate or formalin naught to three times a week) in conjunction with individual treatment of chronic cases. Farms were visited over the course of one year and the impact of treatment on the progression of disease was measured by the prevalence and severity of lesions using the scoring system developed in chapter two.

6.2 Method

6.2.1 Farm selection criteria

Farmer based treatment strategies derived from the previous phone survey (Chapter 5) were summarised, and grouped and formed the selection criteria for the sub-population of the survey herds recruited for the present longitudinal study. Farms were grouped into four main treatment categories: individual treatment only, footbathing treatment only, routine preventative footbathing and individual treatment of chronic cases, or routine preventative and responsive footbathing treatment and individual treatment. The treatment approaches: group one = individual topical treatment only, and group two = preventative footbathing with individual treatment of chronic cases, formed the two groups from which farms were recruited for the current study.

Farm inclusion criteria were as follows: to allow one visit per day only, farms within a two and a half hour drive from Bristol and with a herd of less than 400 cows milked in less than four hours were considered. Rotary parlours and robots were rejected due to the difficulty observing feet closely in the parlour. Only farmers giving consent for the researcher to hose feet off in the parlour where necessary in order to inspect lesions clearly and record treatment actions taken in the month between visits were included. In addition, only farms using cubicle housing were considered for this study in order to standardise the management strategy across all farms and between different treatment groups. Eligible farms in each treatment group were matched in pairs by location (within 50 miles) in order to standardise farms geographically and facilitate efficient visits.

The criteria for group one inclusion (individual topical treatment only) were that farmers practised individual topical treatment of DD only, with no herd level footbathing intervention at all. The criterion for inclusion to group two (routine herd prevention and individual topical treatment of chronic cases) was routine herd level footbathing with either formalin or copper sulphate solutions up to three times a week and individual topical treatment of chronic cases (the frequency of footbathing was likely to change on these farms, in the event of a) flare up and/or b) time of year/housing period). This study was designed to observe the effect of farmer-led treatment intervention and therefore the frequency and quality of individual and herd level treatment intervention was outside the researcher's control. The researcher obtained monthly records of footbathing and individual treatment to ensure the described interventions were being carried out. Group two farms had permanent or semi-permanent footbaths on the exit of the milking parlour. Although some members of the footbathing group used a pre footbath, farmers did not routinely hose feet off in the parlour.

6.2.2 Longitudinal study design

A statistician was consulted to ensure that the power of the data set was not compromised by the number of farms that could be realistically visited once a month by one researcher. In order to balance the frequency of visits to each farm, and taking into account the feasibility of one researcher visiting every farm within a four week period, the maximum number of farms that could be studied per month was sixteen. This allowed one day a week in the office to organise the visit schedule. At an early stage one farm was withdrawn from the study (see 6.2.3) so ten visits to fifteen farms, at four to six week intervals were carried out over a twelve month period summarised in the visit schedule (Table 6.1) totalling 150 visits.

Table 6.1 Visit schedule 2009-10

VISIT 1	VISIT 2	VISIT 3	VISIT 4	VISIT 5	DATABASE CONSTRUCTION	VISIT 6	DATA ENTRY	VISIT 7	VISIT 8	VISIT 9	VISIT 10
DATE 16/2-13/3	DATE 16/3-10/4	DATE 13/4-8/5	DATE 11/5-5/6	DATE 8/6-10/7		DATE 10/8-8/9		DATE 30/9-23/10	DATE 26/9-20/11	DATE 23/11-18/12	DATE 18/1-12/2

6.2.3 Farmer recruitment

Farms eligible to take part were contacted via telephone at the beginning of February 2009 until eight farmers from group one (individual topical treatment only) and eight farms from group two (preventative foot bathing and individual topical treatment of chronic cases) were recruited. In order to ensure farmers were informed about the visit schedule and willing to participate in the project, the basic visit protocol was explained at the recruitment phone call. Four farmers declined to take part in the study due to the perception that the researcher's presence in the milking parlour would interrupt the routine or were not happy for the researcher to hose feet off in the parlour. Four farms in Cornwall, three farms in Devon, three farms in South Wales, two farms in Somerset, two farms in Wiltshire, and two farms in Warwickshire were recruited. Visits in the same or a nearby county were arranged within the same week each month to enable logistical data collection. After the first visit, one farm from group one was withdrawn from the study as the size of herd and speed of milking was too rapid for reliable scoring of lesions in the parlour.

6.3 Visit protocol

6.3.1 Individual cow level assessment in the milking parlour

At each visit during afternoon milking, the hind feet of the whole milking herd were scored for the presence/absence of DD lesion(s) and the stage(s) of lesion(s) as described in chapter 2 (Figure 2.1). Cows were identified by freeze brand number. A head torch was used to illuminate the feet and aid closer inspection. Where necessary, feet were also hosed off in order to inspect the lesion state more closely. On farms where individual treatment of DD was part of their regular routine in the milking parlour individual cases were brought to the attention of the farmer/herdsman in the parlour at the time of detection for ethical reasons. The dates of individual treatment and footbathing were collected to ensure the described intervention was being implemented.

6.4 Data analysis

An Access database was created in order to enter and sort data. Each farm was assigned a unique number identifier and a treatment code according to its overall treatment strategy (one = individual treatment, two = herd prevention/treatment and individual treatment of chronic cases). Data for each farm was entered at a visit level. The presence/absence and stage of lesions for each hind foot for each cow was entered separately for each visit and a farm level prevalence of cows with DD at each visit was calculated. A count of cows with at least one active lesion(s) (stage 1, 2 or 3) on either foot was divided by the herd size to obtain a mean farm level prevalence for each visit. The milking herd size was taken as the herd size on the day of the visit. The farm level status of DD at each visit was calculated in three categories, 1. Stage 0 = none (no lesion), 2. Stage 1, 2, and 3 = active lesion and 3. Stage 4 and 5 = cured lesion. A count of each foot with either none, active or a cured lesion on both hind feet was calculated and divided by the herd size to obtain the proportion of the severity of lesions for each farm at each visit.

Data was transferred into Microsoft Office Excel 2007 to calculate descriptive statistics. The standard deviation, standard error, minimum and maximum for the farm level prevalence of DD at each visit was calculated.

6.5 Results

6.5.1 Farm demographics

The mean milking herd size for the whole study period for the seven farms that applied an individual treatment strategy for DD (group one) was 168 cows (S.D. = 73, S.E. = 29), ranging from 80 – 301. The mean milking herd size for the eight farms that applied a herd level prevention strategy with individual treatment of chronic cases was 155 cows (S.D. = 79, S.E. = 26), ranging from 73 – 305.

6.5.2 The herd level prevalence of digital dermatitis across treatment groups

Figure 6.1 illustrates the mean herd level prevalence of DD for each farm at consecutive visits. The blue lines represent (group one) farms that used an individual treatment approach and the red lines represent (group two) farms that used herd level footbathing and reported treating chronic cases individually. The graph demonstrates the variation in initial prevalence of DD across all study farms. The initial prevalence of DD ranged from eight to forty five percent (Mean = 33%, S.D. = 16, S.E. = 4) between farms, with the exception of one farm in the individual treatment group which had an initial prevalence of sixty nine percent (indicated by blue boxes on the line). Despite declaring individual case treatment when interviewed on the phone, upon visiting this farm it became apparent that regardless of high disease prevalence, this farmer did not actively treat individual cases on a regular basis. This farmer's non-compliant attitude towards treatment was significantly different to the rest of the treatment group and farms overall. Due to a significantly higher observed herd level prevalence of disease on the first three consecutive visits compared to the other farms, this farm is treated as an outlier and removed from further analysis. It is important to note however that despite no treatment intervention on this farm, the level of DD significantly reduced during the grazing period (May – November) to come in line with the other study farms.

With the exception of one farm within the herd treatment group (indicated by red boxes on the line, Figure 6.1), all farms followed a similar seasonal trend where the prevalence of DD reduced significantly and continued to reduce throughout the summer period while the cows were out at grass (April – October). The farm in group 2 which did not follow this trend did not turn high yielding cows out during the summer.

Figure 6.2 depicts the mean prevalence of DD (error bars = standard error) by treatment group which follows a seasonal curved trend. Visit one started in February in the later part of the winter housing period. There was no difference in the mean prevalence of DD between treatment groups at the initial visit (individual mean = 30%, S.E.= 6, herd mean = 31%, S.E. = 4) or at visit four (individual mean= 15%, S.E. = 3, herd mean = 15%, S.E. 5), and the disease prevalence between treatment groups did not differ significantly in visits two (individual mean = 23%, S.E. = 3, herd mean = 20%, S.E. = 5) and three (individual mean = 15% S.E. = 3, herd mean = 18%, S.E. = 5). However after visit four in May shortly after the cows were turned out to grass, the mean herd level prevalence between treatment groups began to diverge. The prevalence of DD in the individual treatment group reduced by 45% compared to a 27% reduction in the herd treatment group between May and June. Between June and August, the disease prevalence in the individual treatment group reduced by a further 45% compared with only 9% in the herd treatment group. At the end of the grazing period, the prevalence of disease plateaued at 5% in the individual treatment group between August and November and at around 10% in the herd treatment group between June and November, before gradually increasing again in parallel through December to January when the cows were again housed.

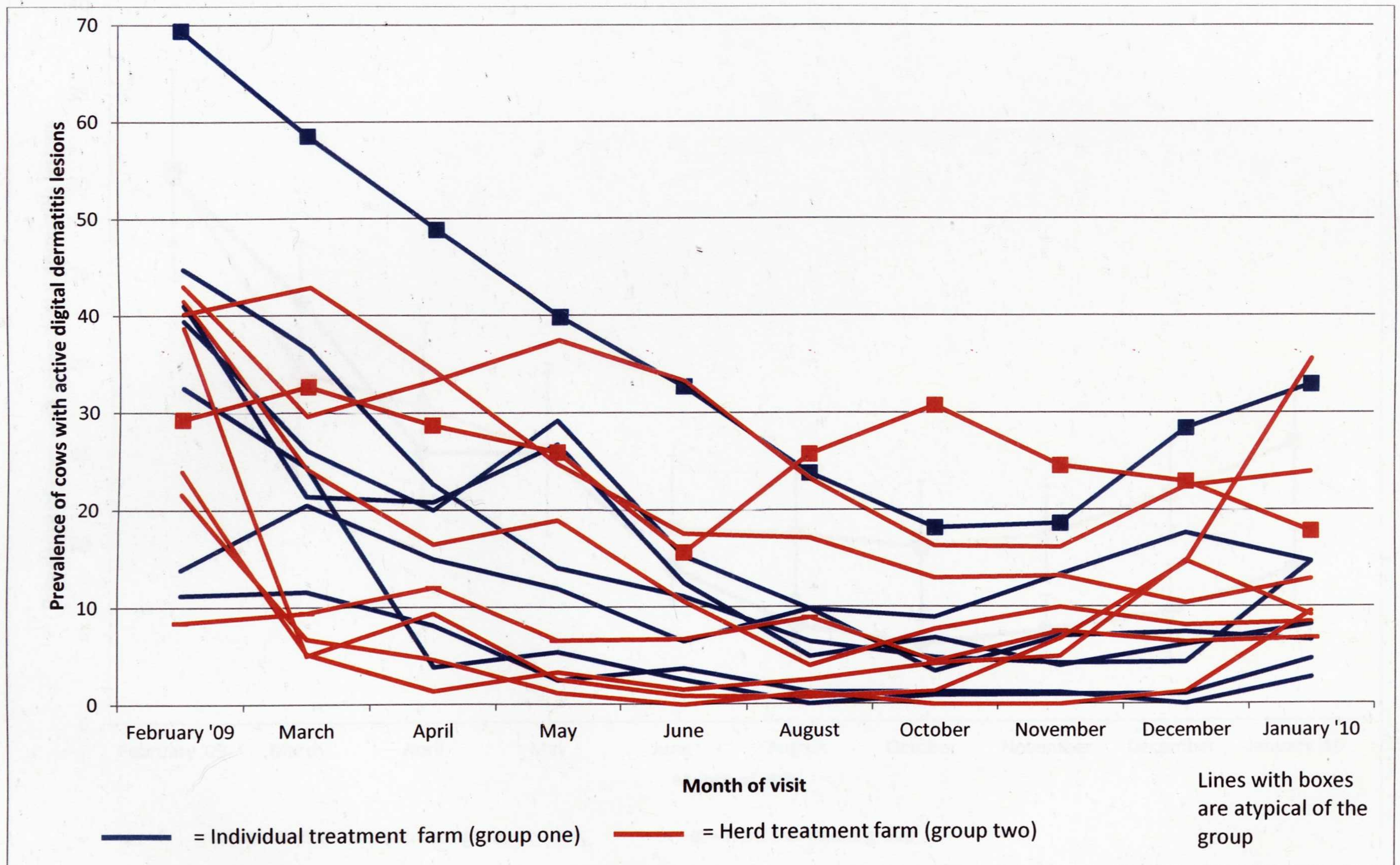


Figure 6.1 The herd level prevalence of digital dermatitis by month for each farm in the study

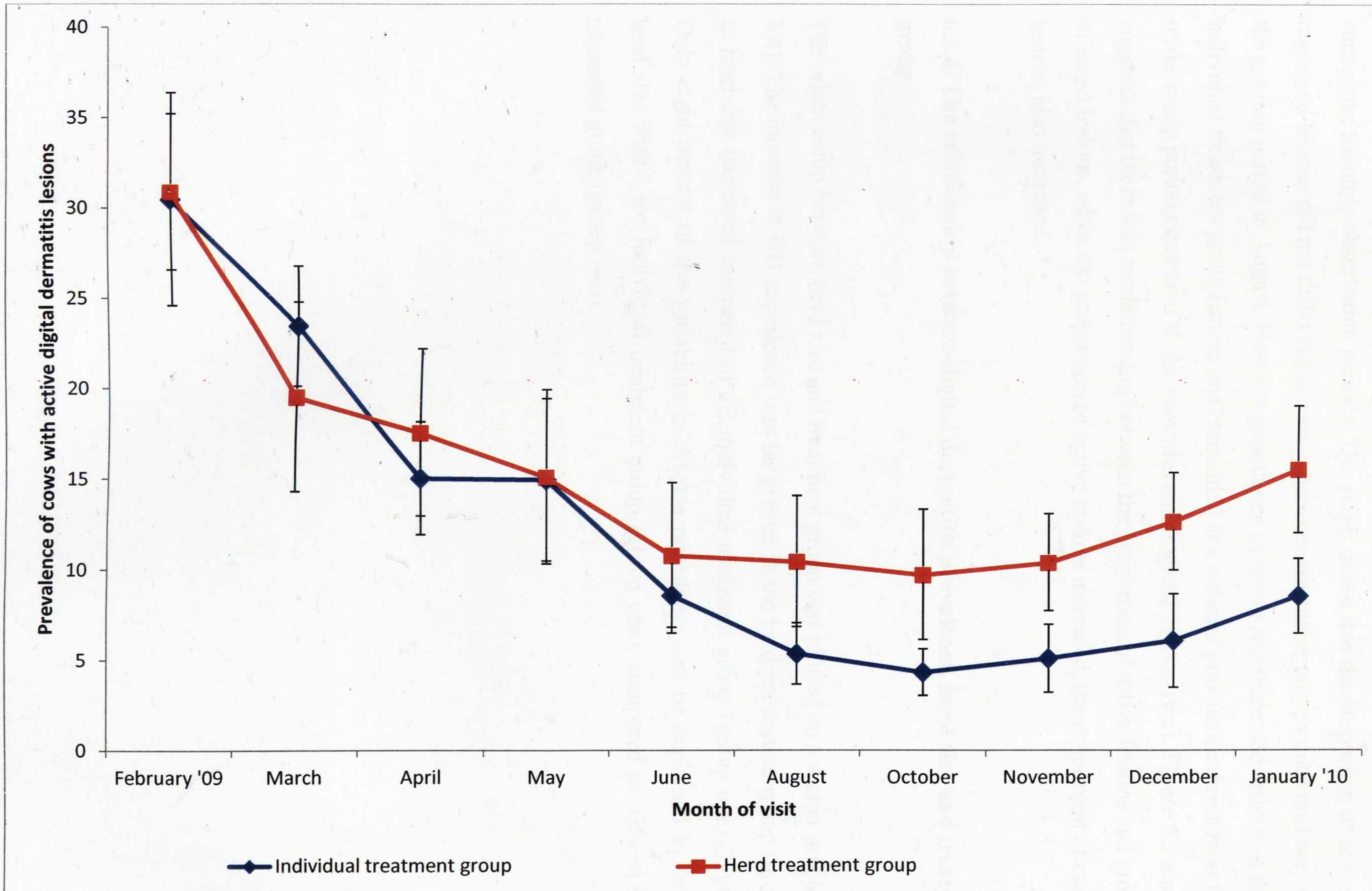


Figure 6.2 The mean prevalence of digital dermatitis within each treatment group at each visit

6.5.3 The herd level severity of digital dermatitis across treatment groups

Figure 6.3 depicts the lesions by status (none, cured or active) in each treatment group over successive monthly observation periods. The graph shows that the proportion of active and regressed lesions did not differ significantly between treatment groups until mid way through the grazing period in August. Here the prevalence of active and regressed lesions in the individual treatment group (group one) remained at a reduced prevalence throughout the rest of the study period compared to the herd prevention group (group two). Figure 6.3 also suggests that there was a relationship between the proportion of active lesions and proportion of cured lesions, when the proportion of active lesions increased, the proportion of cured lesions also increased.

6.5.4. The relationship between digital dermatitis prevalence, herd size and treatment group

The relationship between herd size and treatment group was plotted on a scatter graph (Figure 6.4). The increase in DD prevalence was far greater in the herd prevention group (group two) as herd size increased compared to the individual treatment group (group one) (Figure 6.4). Only eight percent of the variability in disease prevalence can be explained by increasing herd size within the individual treatment group (group one), compared to 33% in the herd treatment group (group two).

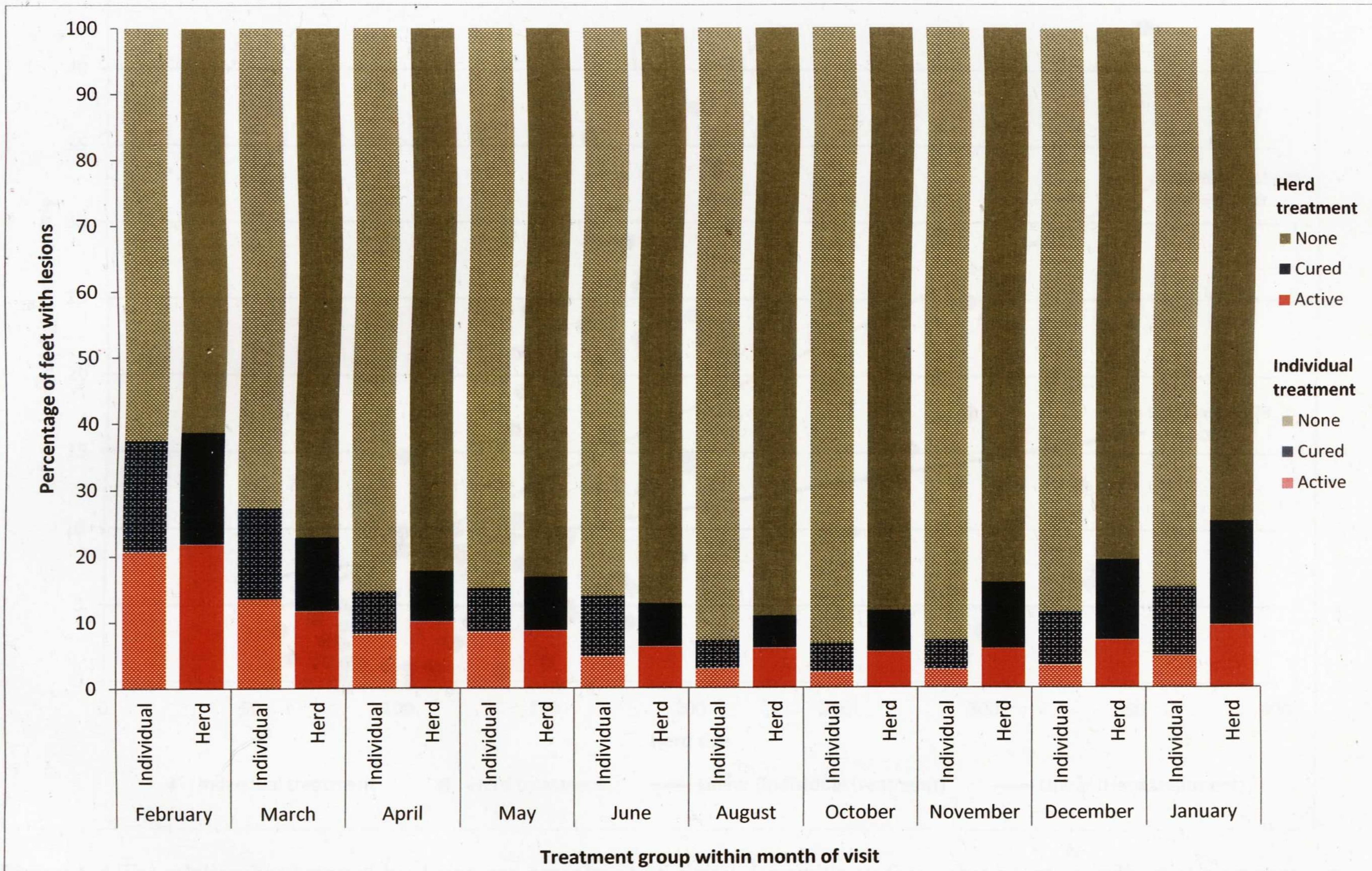


Figure 6.3 The status of digital dermatitis in each treatment group at each visit

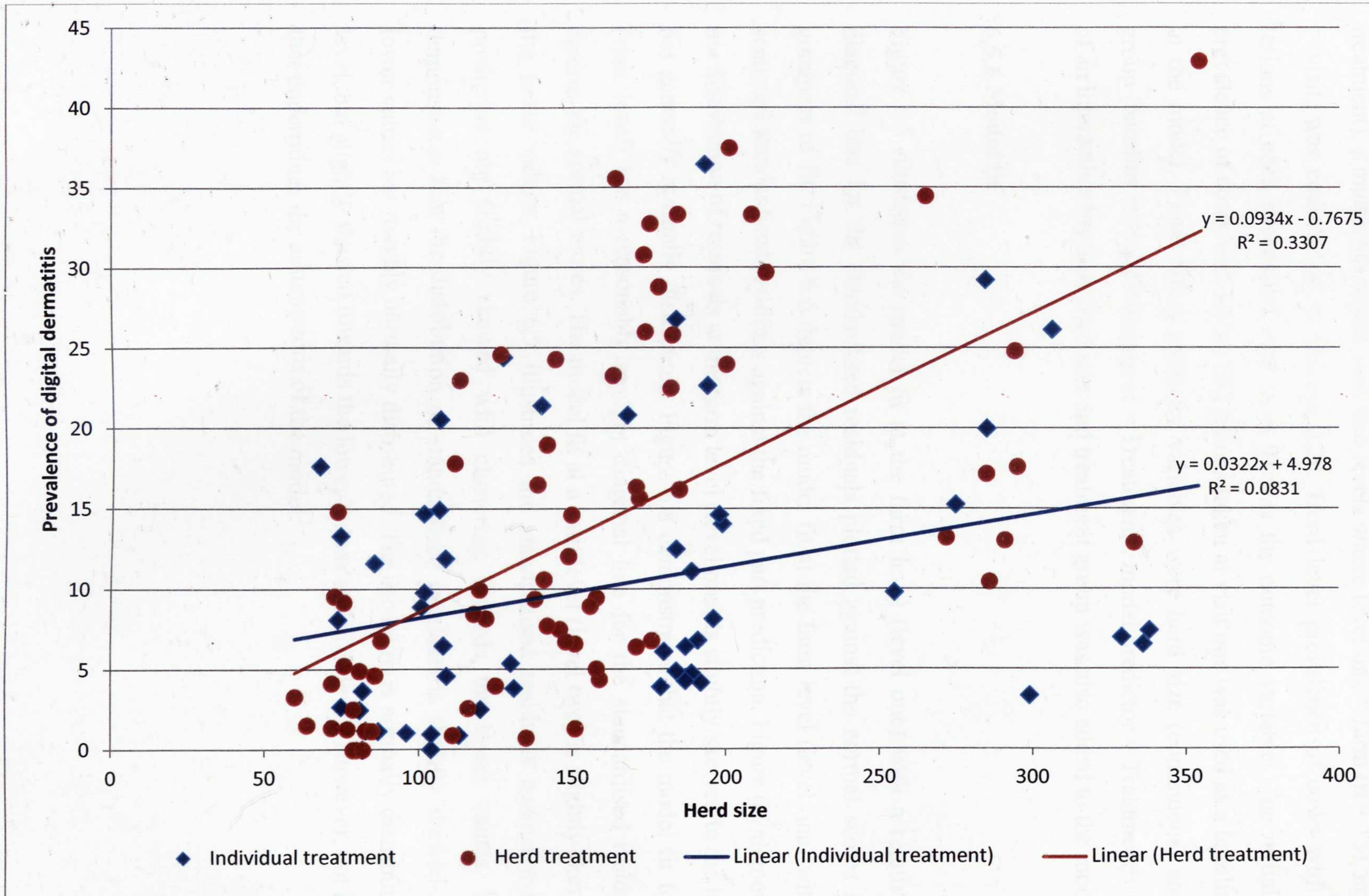


Figure 6.4 The relationship between herd size and prevalence of digital dermatitis on farms that adopt an individual treatment approach versus a herd treatment approach

6.5.5 Multilevel Model building

Given the hierarchical nature of the data where ten consecutive visits to fifteen farms are nested within two treatment groups (Treatment[1] = individual treatment; Treatment[2] = herd treatment), a multilevel model with two levels where level one = farm (n = 15), and level two = visit, was constructed in MLwin 2.20. Herd level prevalence of cows with active DD lesions at each successive visit (n = 9) was the outcome variable. The initial herd level prevalence of cows with active DD lesions taken at visit one was used as a baseline predictor in the model. Fixed effect predictor variables were herd size (continuous) and treatment group (baseline reference treatment = Treatment[1], model predictor = Treatment[2]). The impact of an interaction between herd size and treatment group was also added to the model.

6.5.6 Model fit

Figure 6.5 illustrates the model fit at the farm level (level one) with a relatively straight diagonal line for the standardised residuals plotted against the normal scores indicating a goodness of fit. Figure 6.6 depicts the model fit at the farm level (level one) with randomly scattered standardised residuals against the fixed part prediction. Figure 6.7 demonstrates that the distribution of residuals at the farm level (level one) is slightly skewed to the lower values but generally normally distributed. Figure 6.8 demonstrates that the model fit for level two (visit level) has a reasonably straight diagonal line for the standardised residuals plotted against the normal scores. The model fit at a visit level (level two) is slightly skewed towards the lower values. Figure 6.9 illustrates the standardised residuals against the fixed part prediction are slightly skewed with clustering towards the lower values. Figure 6.10 demonstrates that the distribution of standardised residuals is slightly skewed towards the lower values but roughly normally distributed. The model fit is normally distributed at a farm level, but slightly skewed towards the lower values at a visit level. However, not to the extent that undermines the assumptions of the model.

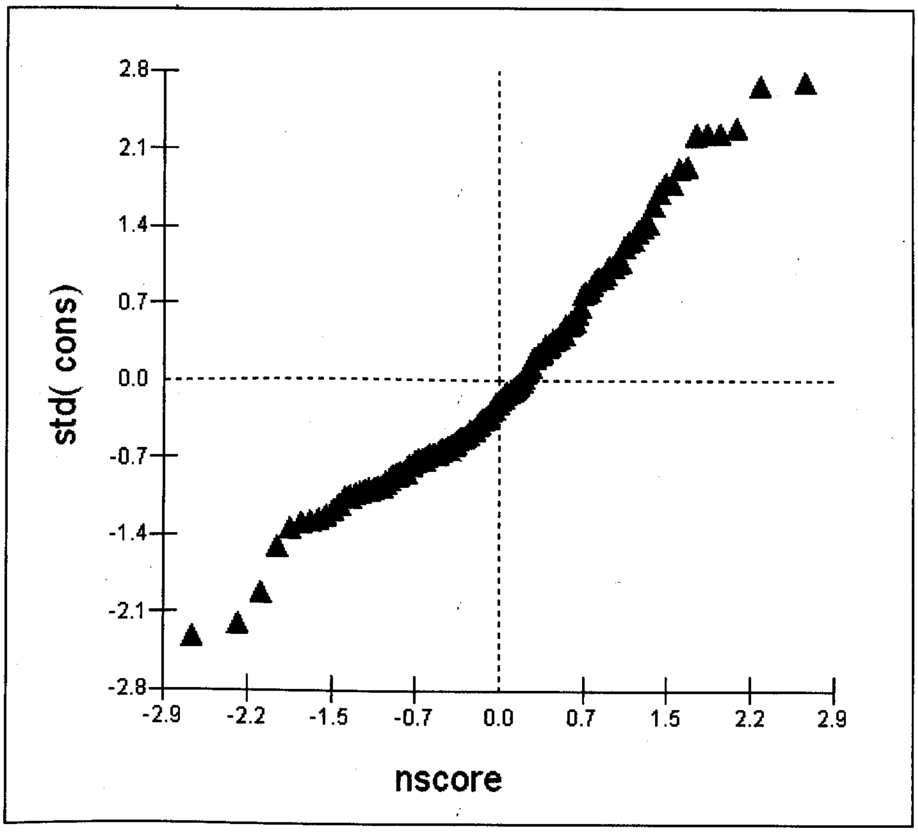


Figure 6.5 Standardised residual against normal scores at farm level

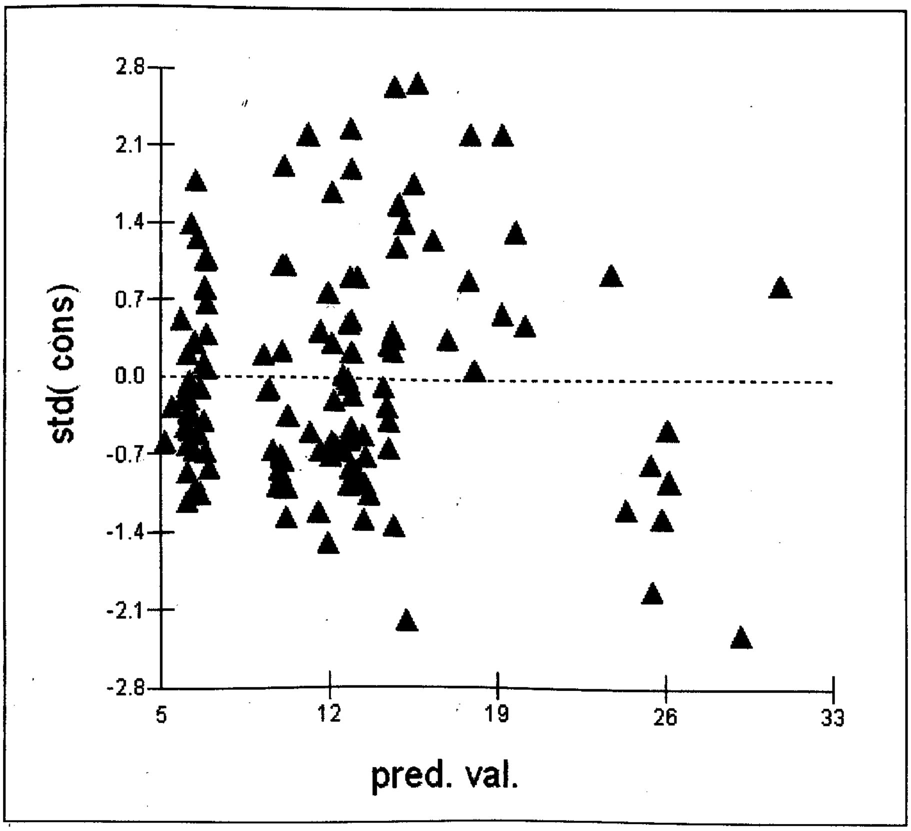


Figure 6.6 Standardised residual against fixed part prediction at farm level

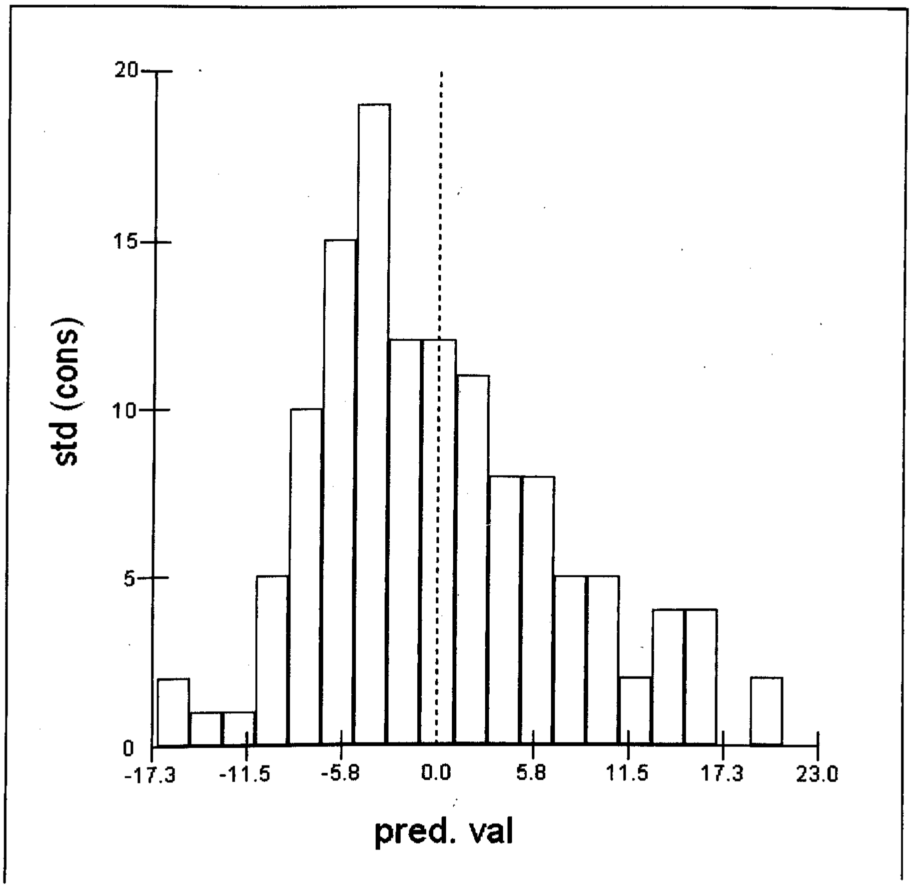


Figure 6.7 Histogram for the standardised residuals at farm level

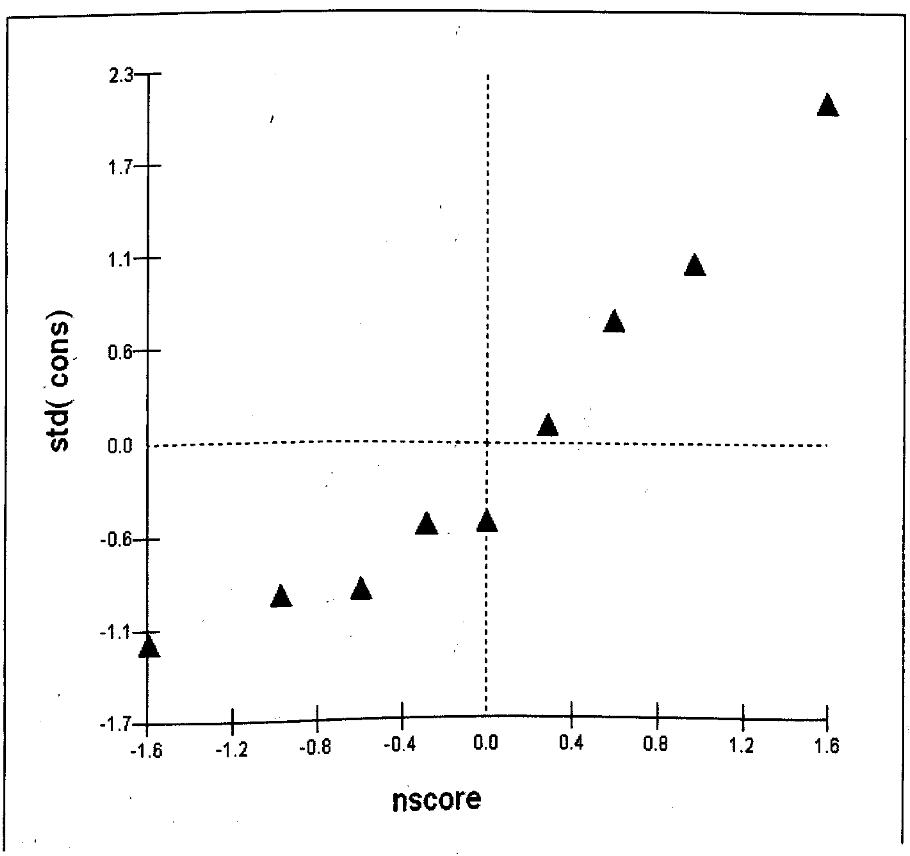


Figure 6.8 Standardised residual against normal scores at visit level

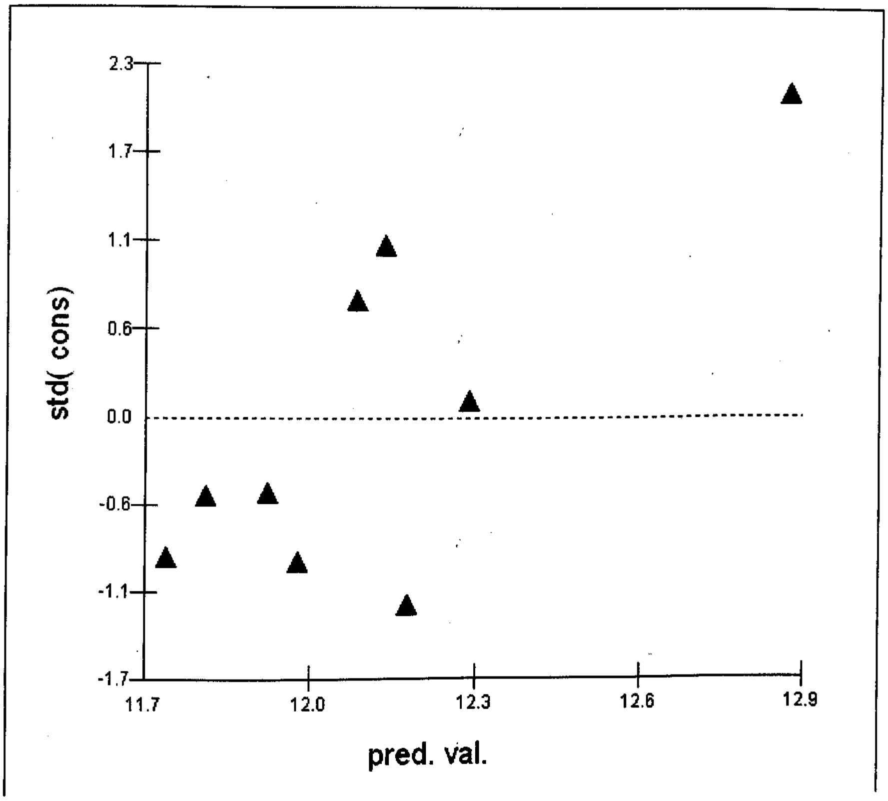


Figure 6.9 Standardised residual against fixed part prediction at visit level

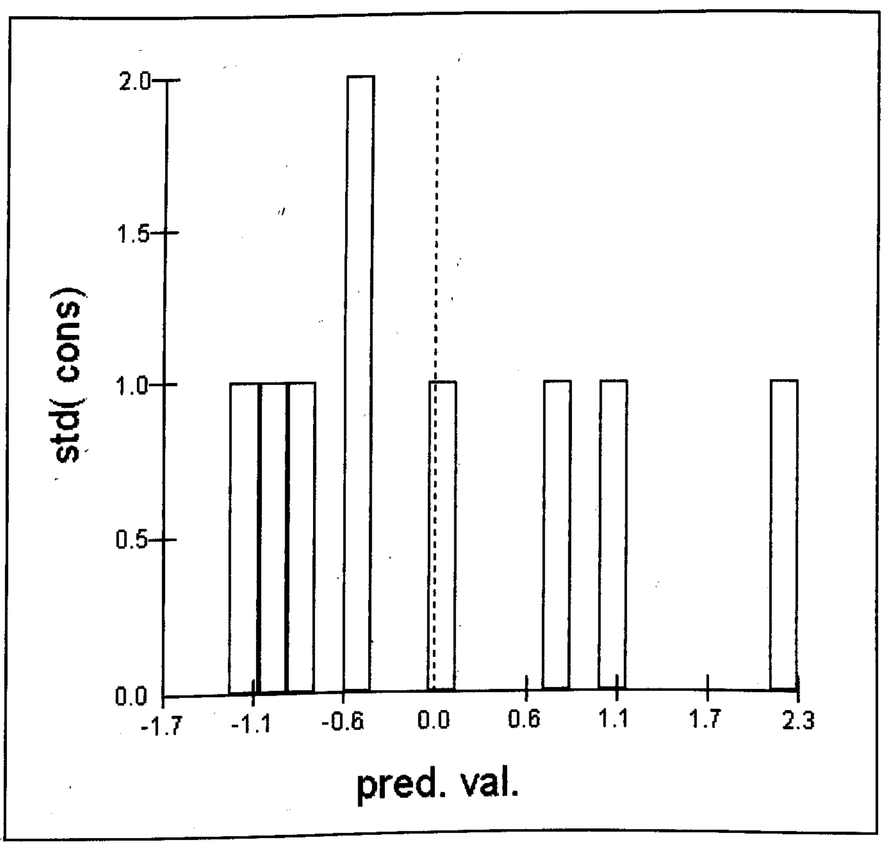


Figure 6.10 Histogram for the standardised residuals at visit level

6.5.7 Model predictions

Table 6.3 presents the results of the model. Figure 6.11 illustrates the model equation in MLwin 2.20. The model indicated that the baseline herd level prevalence of DD for each farm, measured at the initial visit, was a significant predictor of disease at subsequent visits ($p < 0.05$). Herd size on its own had no significant impact on the prevalence of DD. However this variable was retained in the model due to a highly significantly interaction between herd size and treatment². The model indicated that the prevalence of DD increases with increasing herd size on farms that footbath at a herd level (group two) (Treatment², $p = < 0.01$). Figure 6.11 illustrates the effect of herd size and treatment group on the prevalence of disease. As herd size increased, herd treatment² had far less of an effect on the prevalence of the disease than individual treatment¹ ($p < 0.05$). However, treating at a herd level had a marginally more protective effect than treating at an individual level in herds with less than 100 cows ($p = < 0.05$, see Figure 6.11). This model suggests that on the study farms with herd sizes of above 100 cows, this level of herd level prevention was not as effective at controlling the disease compared to individual treatment (Figure 6.11).

As the initial disease prevalence and treatment approach have a significant impact on variability of disease, the variation not presented in the model between farms was small (12.9), whereas the variability between visits within farms was large (59.65). The variation within farms was not significant at 17% (ns), compared to a highly significant visit variation of 83% ($p < 0.01$).

Table 6.2 Management factors associated with increased prevalence of digital dermatitis

Variable	Coefficient	CI	P-value
Intercept	*3.41*	*2.83*	*ns*
Initial DD prevalence	0.16	0.07	>0.05
Herd size	0.01	0.02	ns
Treatment²	-6.9	3.41	>0.05
Treatment²*Herd size	0.07	0.02	>0.01

Farm variation = 12.9 (17%, ns) (variation between farms)
Visit variation = 59.65 (83%, >0.01) (variation between visits within farms)
Initial DD prevalence and Herd size are continuous variables and treatment group is binary (Treatment¹ = reference individual treatment, Treatment² = herd treatment).

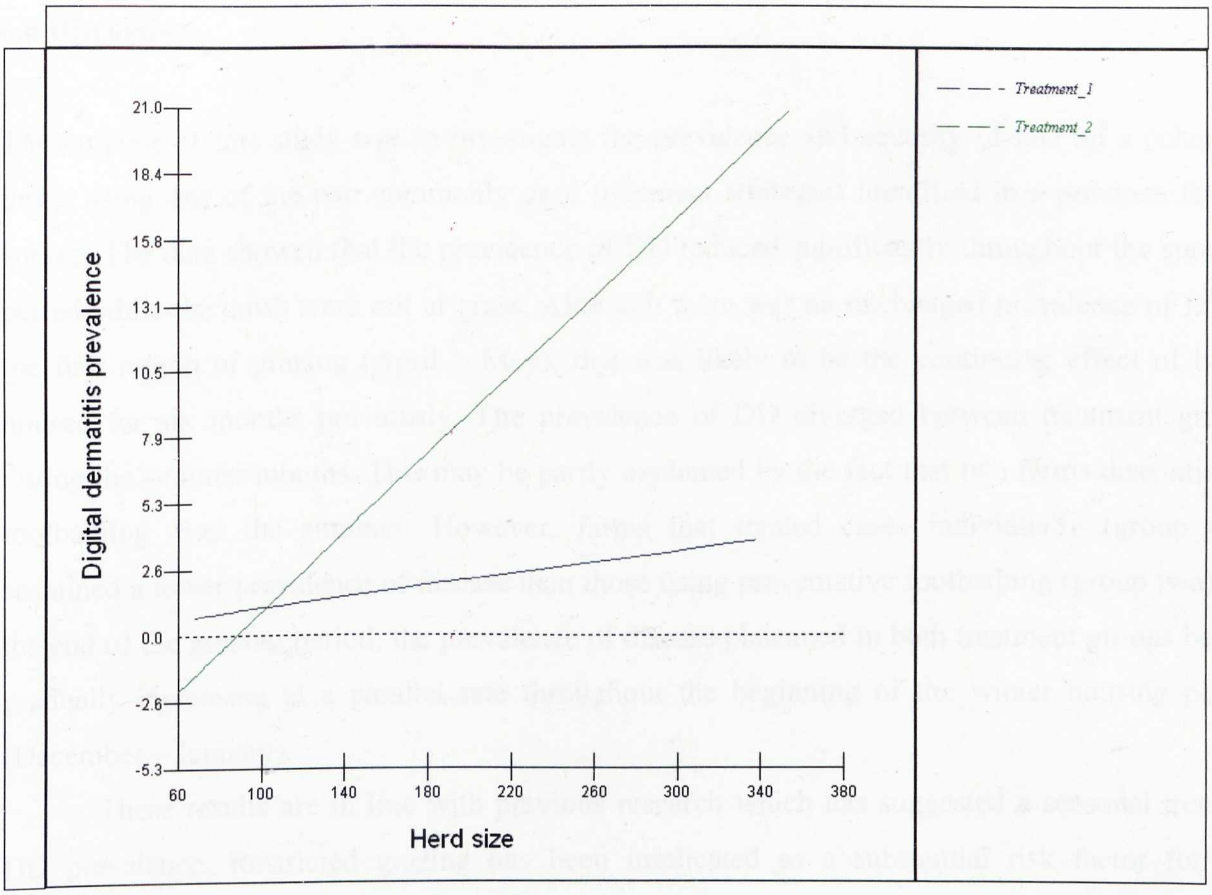


Figure 6.11 The interaction between herd size and digital dermatitis prevalence predicted by the model using individual treatment (1) compared with herd treatment (2)

6.6 Discussion

The purpose of this study was to investigate the prevalence and severity of DD on a cohort of farms using one of the two commonly used treatment strategies identified in a previous farmer survey. The data showed that the prevalence of DD reduced significantly throughout the summer period while the cows were out at grass. Although there was an unchanged prevalence of DD in the first month of grazing (April – May), that was likely to be the continuing effect of being housed for six months previously. The prevalence of DD diverged between treatment groups during the summer months. This may be partly explained by the fact that two farms discontinued footbathing over the summer. However, farms that treated cases individually (group one) sustained a lower prevalence of disease than those using preventative footbathing (group two). At the end of the grazing period, the prevalence of disease plateaued in both treatment groups before gradually increasing at a parallel rate throughout the beginning of the winter housing period (December – January).

These results are in line with previous research which has suggested a seasonal trend to DD prevalence. Restricted grazing has been implicated as a substantial risk factor for DD (Frankena et al., 1991; Wells et al., 1999; Somers et al., 2003, 2005a). One recent study showed how cows become less susceptible to DD as they spend more time on pasture compared to cows housed indoors (Onyiro et al., 2008).

It is interesting to note that the level of DD significantly reduced during the grazing period despite a lack of individual treatment intervention on one farm. Previous research has found that seventy five percent of lesions spontaneously regressed during the grazing period despite no treatment intervention (Manske et al., 2002). Future intervention studies should compare the rate of spontaneous regression of lesions when cows are removed from the underfoot anaerobic housing environment and close proximity to each other which facilitates cow to cow transfer.

Applying a multilevel model to the data showed that the initial disease prevalence on each farm was a significant predictor of disease throughout the study period. There was small between farm variation in disease whereas the between visit within farm variation was large. Variables not included in the model may explain the large visit variation. Previously identified risk factors for DD such as the lack of grazing period, length of the winter housing period and level of underfoot hygiene may explain at least in part, large visit variation.

Herd size had no significant impact on disease prevalence as an independent predictor. However, there was a highly significant interaction between herd size and treatment group across the whole study period. As herd size increased above 100 cows, the protective effect of footbathing at a herd level using copper sulphate or formalin up to three times a week was less effective than treating with individual topical treatment. As herd size and prevalence of disease increased, the model suggested that individual case by case treatment was more effective than this level of footbathing. The DD prevalence in the herd treatment group (group two) was not attributed to bigger herd sizes alone. The mean herd size and distribution of herd sizes between treatment groups did not differ. Recent research into common dairy cattle diseases including lameness suggests that the herd level disease prevalence tended to increase as herd size increases (Hill et al., 2009). This result might be explained by a lower exposure level to pathogens in smaller herds (Frankena et al., 1991).

There are several possible reasons why disease prevalence did not decrease as much under the herd level prevention strategy compared to farmers that treated individual cases. Firstly, an intrinsic part of the study was that the researcher identified individual cases of DD at each visit in the milking parlour. On farms where individual treatment of DD was part of their regular routine in the milking parlour, for ethical reasons individual cases were brought to the attention of the farmer/herdsman at the time of detection. This would have more of an impact on farmers who treat at an individual level compared to farmers who were inclined to manage the disease at a herd level. Identifying lesions in the parlour would also have had more of an impact on proactive farmers that diligently treat individual cases. Each farm received a copy of the data collection sheet highlighting the individual cases of DD after each visit. Farmers using herd level intervention therefore had the opportunity to change their footbathing regime according to disease prevalence. The impact this and the researchers presence had on each farm would be influenced by the motivation of the individual farmer. This was not measured as part of the present study. In order to reduce the influence of the researcher and data feedback in future, the study objectives and data feedback would have to be withheld from the farmer until the study period.

The presence of a footbath on a farm can be an admittance of an infectious foot disease problem. It has been argued that the installation and maintenance of a footbath requires just as much time as maintaining hygienic underfoot conditions on the farm (Nuss, 2006). A recent cross sectional study across fifty Danish farms found that herd size and the use of footbaths were herd level risk factors for DD (Ettema et al., 2009). In cases where footbaths were not regularly used, the odds of DD were half of that compared to a herd that regularly used footbaths (Ettema et al., 2009). This suggests that the absence of a footbathing strategy may indicate the absence of a DD problem. Improper footbath management could also facilitate the spread of DD (Zemlijic, 2004). Specifically, infrequent refreshing of footbathing may give the causative organisms the opportunity to build up, thus facilitating spread between cows (van Amstel et al., 1995).

The present study followed herds footbathed up to three times a week with 5% copper sulphate or formalin as this is common practice by farmers in the UK. However the present model suggests that this frequency of administration is not as effective as an overall individual treatment approach. Periodic implementation of footbathing has previously been identified as a risk factor for digital skin diseases (Somers et al., 2005a). Thomsen et al., (2008) evaluated three copper sulphate based solutions and found no effect on percent cured or percent new infections for any of the solutions administered twice a week for a period of eight weeks. Klaas et al., (2009) evaluated the effect of KlingonBlue and copper sulphate once a week for an eight week period and found no significant effect of either footbathing solution. The author suggested that weekly interventions are not frequent enough to prevent or cure the disease.

There is more evidence to suggest that footbathing is efficacious when administered daily. Bergsten et al., (2007) reported a reduction in the prevalence of DD over a four month period where cows walked through the footbath twice a day using copper sulphate. Similarly Manske et al., (2002) reported the affect of copper sulphate used twice daily over six months on the cure rates of DD, although this study reported no preventative effect on healthy feet. It is therefore plausible that a more intensive footbathing regime could be effective.

Treatment efficacy can be site specific (Hernandez et al., 2000). Lesions further away from the foot extremity, at the dewclaws for example, may not be penetrated by footbathing. As the footbathing strategy was under the farmers' control, the detail of the routine varied from farm to farm, having an impact on the treatment efficacy. These details were not accounted for in the model. For example, although farmers in this study reported using a pre wash footbath, feet were not hosed down in the parlour before entering the solution. The cleanliness of the feet will have an impact on both the solutions ability to penetrate the lesion site and the length the footbath remains effective (van Amstel et al., 1995). The cleanliness of feet was not included in this model. Faecal contamination is known to inactivate most footbath solutions (Thomsen et al., 2008b). The efficacy of the footbath can be reduced where the solution is not changed after 200 cows (Blowey, 1994; Hartog et al., 2001). This problem can be exacerbated with increasing herd size.

Farmers who implement herd level treatment may also be less likely to treat cases individually as they perceive that they are managing the disease by footbathing. This effect can be exacerbated in the case of increasing prevalence and herd size due to the time and labour associated with detecting and treating cases individually. However the frequency and quality of individual and herd level interventions in each group were not considered in the model. For example, within the herd level group (group two) there were likely to be farmers that continued to adopt a proactive individual treatment approach as well as farmers that relied heavily on footbathing, not inclined to treating cases individually. Further analysis is therefore necessary to establish the relationship between the frequencies of individual treatment interventions in conjunction with footbathing on the disease prevalence.

Footbaths are perceived to be the quickest and most successful method of controlling contagious foot diseases (Nuss, 2006). However, farmers that footbath may be unaware of the disease prevalence in their herd because herd intervention negates the need to monitor individual cases. Limited record keeping has been previously associated with a higher level of lameness (Bell, 2006). Farmers underestimate the prevalence of lameness (Wells et al., 1993, Whay et al., 2002b and Bell et al., 2006). A recent survey found that despite all farmers reporting having to manage the disease; only ten percent perceived DD to be a major problem (see Chapter 5). If farmers underestimate the disease prevalence, they will not perceive it to be a problem and consequently are less likely to take action to control it (Whay, 2002b).

If farmers are aware of a continued high prevalence of disease despite their efforts in footbathing, cognitive dissonance may explain why they continue to use a sub-optimal managing strategy. Cognitive dissonance suggests that people change their beliefs about how effective something is to match the behaviour of carrying it out, even though the behaviour maybe sub-optimal. Farmers endorse footbathing because it is an ideal management tool: practical, time effective and manageable within the busy farm day. Interestingly in a recent study into farmer management of footrot and interdigital dermatitis in sheep, Wassink et al., (2010) found that farmers endorsed using footbathing to manage these diseases because they already used the strategy despite also reporting being dissatisfied with its efficacy. Farmers indicated that they would prefer to use fewer individual treatments, despite the fact that farmers that used this strategy reported excellent results (Wassink et al., 2010).

6.7 Conclusion

Identifying both practical and effective interventions are a prerequisite for the control of DD on farm. The concept of an optimal point at which to switch from one treatment strategy to another is critical for farmers to understand, if control is to be improved. Switching between individual case management and blanket herd treatment is practised by many farmers in the UK. The present model suggests that as herd size and DD prevalence increase, switching to an individual treatment approach is optimal. The treatment actions farmers take need to be based on confirmed effectiveness of the intervention, as opposed to purely practical consideration.

Chapter 7

General Discussion

7.1 Introduction

The objective of this project was to investigate the reliability of novel and existing ways of identifying DD in individual cows within a herd in order to identify a practical means of monitoring the development of lesions on a regular basis. Furthermore, a farmer survey was carried out to establish the nature and scope of existing prevention and treatment strategies implemented by a group of UK dairy farmers, revealing that farmers use a variety of different methods to manage the disease. Seventy seven percent of farmers footbath but report treating chronic cases individually, whereas four percent footbath only with no individual treatment. Nineteen percent of farmers treat cases only at an individual level. Following on from this survey fifteen farms were recruited to carry out an on farm observational study monitoring the prevalence of DD given two commonly used farmer controlled management strategies at an individual or herd level. The monitoring system developed to detect lesions in the parlour was used as the outcome measure to obtain the herd prevalence of DD at monthly to six week intervals over a year's study period. This final chapter brings together the project findings in the context of existing literature and discusses the study's limitations, making practical recommendations, and suggesting directions for future research.

7.2 Detecting digital dermatitis in the parlour

Screening cows in the parlour by washing their hind feet and carrying out a visual inspection for DD was shown to be a reliable method of monitoring individual cases in a research setting. This study however did not measure the feasibility of farmers carrying out this protocol. Assessing the time taken to carry out this procedure during the milking on a variety of parlour types and herd sizes is recommended, in order to establish the feasibility of this procedure as a regular monitoring strategy in terms of its potential disruption to the milking routine, the labour required and the time taken to carry it out.

Regular monitoring and treatment of individual cases of DD in the milking parlour enables the farmer to monitor the effectiveness of prevention strategies, adjust management accordingly, and reduce the infection reservoir within the herd. Furthermore, cleaning feet regularly will make DD identification easier and remove the anaerobic underfoot environment.

It is evident from the survey that farmers are willing to use the milking parlour as an opportunity to assess the health of feet. Eighty two percent reported detecting DD here. A further survey could establish the methods farmers use to identify lesions in the parlour and the frequency with which such inspections are undertaken to identify at what stage farmers are detecting the disease. Intervention should focus on facilitating the uptake of regular parlour screening by famers to encourage early individual treatment. This would provide a benchmark for use in training and dissemination of best practice.

7.3 Thermography

Thermography has shown potential for identifying an elevated skin temperature associated with inflammation due to foot disorders. This measure benefits from being objective, non invasive and rapid application. The present study identified a high level of cows with foot disorders as true positives, but also a number of false positives. The reliability of a measure will depend on its purpose. When dealing with an infectious disease such as DD, it is imperative to identify all cows with foot disorders at the risk of including several healthy cows, rather than miss a cow with a lesion. Furthermore, this study suggests the optimal trade off between sensitivity and specificity is attainable without having to clean or lift the foot first. This enables a rapid, practical means of identifying potential cases for treatment.

The current high cost of thermography equipment constrains its use to a research context where it may have several applications. This measure could be used to observe the development of foot disease over time, in order to identify a temperature threshold for early treatment. A recent study following the progression of experimentally induced DD lesions found that spirochaetes can reach the deeper layers of the epidermis and dermis by day eight of lesion development, and are found in increasing numbers by day seventeen (Dopfer et al., 2011). Once treated, a lesion may therefore appear resolved on the surface of the skin yet harbour DD associated bacteria in sebaceous glands and hair follicles (Dopfer et al., 2011, Carter et al., 2009). It is unknown whether topical oxytetracycline can penetrate through the skin. Histopathology can be used to establish whether the surface temperature of the skin correlates with the infection status under the skin. In this case, thermography may provide insight into the status of infection under the skin by monitoring the temperature change elicited by an inflammatory response caused by spirochete colonisation through the epidermis and dermis. In summary, thermography may provide a useful tool alongside clinical scoring of lesions, microbiological and histopathological analysis to generate insight and advance our understanding of the disease process, and the effectiveness of treatment.

7.4 Locomotion scoring and behavioural observation

Locomotion scoring is an inherently subjective measure with a degree of interpretation and manpower required to carry it out. Currently locomotion scoring systems advocate treatment once a cow is scored lame. However only eighteen percent of cows with DD exhibited an obvious limp classifying them as lame during the present study. This may result in cows with DD going undetected and untreated, reducing the likelihood of recovery and increasing the risk of recurrence. For example, the prevalence of DD will be underestimated in herds that rely purely on locomotion scoring to identify cases for treatment.

Farmers also reported DD to have an inconsistent effect on locomotion, implying the disease was difficult to detect using this method. The survey suggested that fifty percent of farmers identified DD cases for treatment using lameness, however only eighteen percent would investigate a cow exhibiting tenderness. Farmers prioritise lame cows for treatment. Locomotion scoring might be more sensitive for DD detection if the threshold criteria for treatment were lowered to include a category including tenderness. The current data suggests this is possible without substantially increasing the number of false positives. However further research on a larger cow sample is necessary.

Changes in behaviour can be an indicator and behavioural outcome of a specific disease or combination of diseases. This study developed a comprehensive ethogram which was used to observe the effect foot diseases have on the dairy cow's overall behaviour during a ten minute observation period. Using the ethogram several behavioural signs attributed to DD specifically were identified, including lifting and resting of the affected limb. Likewise, twenty one percent of farmers surveyed reported using these specific behavioural indicators for DD. Assessing the reliability (sensitivity and specificity) of these behavioural indicators on farm, is recommended.

The ten minute behavioural observation period also identified a significant reduction in the frequency and occurrence of regurgitating and ruminating behaviour in cows with DD. This has direct implications for dairy cattle health, welfare, and production and should be used to raise awareness amongst farmers to act as a motivator to implement on farm disease prevention strategies.

Investigating risk at an individual cow level should help to explain why some cows develop DD lesions and others do not within an apparently similar environment. Future research should focus on the interface between individual cow behaviour and her environment as risk for disease development.

7.5 Farmer survey

The farmer survey carried out to identify the management strategies used in the UK to control DD identified dissociation between the farmers' attitude towards the disease and the impact the disease has on the cow and farm business. For example, although farmers reported far reaching consequences of the disease with a self reported annual incidence of nineteen percent, only ten percent considered DD to be a major problem.

The survey also revealed dissociation between reported management strategies and action taken on farm. Footbathing is the default strategy used in an effort to control DD, however many farmers start footbathing as a reaction to the disease as opposed to a regular preventative routine. The frequency of footbathing reported by farmers responding to the survey ranged from twice a day to once every two months with antibacterials (copper sulphate or formalin), once and twice a week frequencies being the most common. Evidence from the longitudinal farm survey (chapter six) suggests this is inadequate as, either a prevention or treatment strategy, particularly as prevalence of DD and herd size increase.

The farmer survey also revealed that formalin or copper sulphate was used four times more commonly than antibiotics; however in cases where a disease flare up occurred and an antibiotic was administered, lincospectin was commonly used. The reported dosage for all agents varied considerably with only a small proportion of farmers' footbathing all groups of cows. These results highlight a degree of trial and error on farm. Overall farmers said they viewed footbathing as an important prevention strategy (rather than a treatment). However footbathing in many cases was implemented as a treatment, in reaction to the disease. Farmers do not appear to be distinguishing between a prevention and treatment strategy.

Discourse analysis revealed that forty six percent of farmers viewed individual topical treatment as more effective than footbathing the herd. Although it was beyond the scope of this survey to record the number of individual and herd treatment interventions, farmers revealed there were different levels of emphasis placed on the priority and regularity of carrying out individual treatments. When DD is managed at a herd level the focus can shift away from monitoring and treating individual cases.

Although fifty six percent of farmers that footbathed reported treating individual cases of DD that were detected, it was beyond the scope of the study to monitor how many individual cases this translated into in relation to disease prevalence. Across all farms copper sulphate was the commonly used topical alternative (31%) to recommended oxytetracycline (58%). From the farmers' descriptions of lesions at the time of detection it appears that fifty two percent of all lesions were being detected at an early (erosive) stage of infection, however only sixty four percent of farmers reported treating a lesion at the time of detection.

Historically the use of systemic antibiotics has been controversial due to the cost involved and the fact that DD has been viewed as a superficial localised skin disease (Weaver et al., 1981, Dopfer, 1994). However, in practice fifty one percent of farmers reported having used systemic antibiotics for the treatment of DD, ninety six percent of which considered them effective. Recent histopathological evaluation has found spirochetes in deep layers of the epidermis and dermis (Dopfer et al., 2011) which indicates an erosive function through the skin, but it is not yet known whether topical treatment, including oxytetracycline, can penetrate treponemes residing deep in the epidermal tissue. Therefore it would be logical to investigate the long term effect of using topical versus systemic antibiotics.

Research into footrot in sheep has demonstrated the benefit of early intervention using systemic and topical antibiotics for reducing the duration of the disease and the likelihood of recurrence (Kaler et al., 2009). A recent case study investigated the hypothesis that DD can be eradicated from a group of cows by using a long-acting systemic antibiotic treatment, and topical five percent formalin disinfection, and removing any direct or indirect infection reservoir by removing contact with infected animals at grass (Bell et al., 2011). Two cows with granulomatous DD lesions at the beginning of the study resolved after treatment and no cows at the end of a twenty two week study period presented lesions. However, the group was not followed after re-entering the housing. Further research is necessary to determine whether this protocol is effective for long term housed cattle. A longitudinal study following the recovery and reoccurrence of the disease in a herd given topical antibiotic treatment, versus topical and systemic antibiotic treatment with a blind randomised control trial using clinical, histopathological and/or thermography evaluations, would help to address this question.

Farmers advocate the most important prevention measure as the maintenance of clean feet, through a regular scraping routine; footbathing or manually hosing down feet. However this study was unable to assess the uptake of these measures. The importance of maintaining hygienic feet in order to reduce the anaerobic environment surrounding the feet have been well documented (Vink, 2006, Bell et al., 2009). Nowrouzian et al., (2011) demonstrated that as hygiene got worse on the lower portion of the hind foot below the accessory digits of cows, DD prevalence increased. Thomsen et al., (2011) suggests that an automatic washing system can decrease the prevalence of DD in commercial herds. There is a trade off between the time taken to manually wash cows' feet on a regular basis and the relative effectiveness of an automatic washer. Recommendations for future work focussing on prevention would be to assess the relative feasibility of maintaining clean feet though an optimal scraping routine, compared to hosing feet down manually or using an automatic washer.

This survey identified that farmers have adopted a multitude of intervention strategies in an attempt to reduce DD on their farms. At the same time, eighteen percent of farmers are still dissatisfied with the current understanding of the disease process and the related prevention and treatment options available. Longitudinal on farm studies are necessary to test the relative effectiveness of farmers' interventions.

7.6 Farmer defined treatment strategies

Modelling the impact of initial DD prevalence, herd size and treatment strategy on the herd level prevalence of DD across fifteen study farms over a one year period found that DD prevalence increased substantially with increasing herd size on farms that managed the disease at a herd level, compared to farms that treat individually, which retained a lower level of disease prevalence. Footbathing up to three times a week using an antibacterial solution (copper sulphate or formalin) was found to have less of a protective effect as prevalence and herd size increased. However, the model indicated that treating at a herd level was more protective than treating at an individual level in herds with less than 100 cows. Conversely the model suggested that on the farms studied with herd sizes of above 100 cows, herd level intervention at this level was not as an effective control measure as treating cases individually. As such it would be optimal to switch to an individual treatment strategy as DD prevalence and herd size increases, as these two factors exacerbate transmission of infections between cows.

The initial DD prevalence was found to be a substantial predictor of disease prevalence at subsequent visits throughout the study period with large variation between visits and between farms. The prevalence of DD corresponds to the level of exposure to spirochetes and other associated pathogens and infection pressure within the herd. The within farm variation was small, further indicating that individual farm management strategies did not substantially reduce the prevalence of the disease once the disease is present. The degree to which these strategies are effective depends on the starting prevalence.

A seasonal trend was evident, although new infection was found to occur all year round, but at a lower rate during the grazing period. These results concur with previous studies which suggest the dependence of the disease process on the housing environment (Somers, 2004, Vink, 2006 and Bell, 2006). Investigating the therapeutic benefits of grazing is recommended, in particular, the impact on foot hygiene, cow to cow transmission, diet, and the rate of spontaneous lesion recovery.

This model was a preliminary effort to compare the impact of farmer defined intervention on the herd level prevalence of DD. Its application is limited regarding the variation in frequency of footbathing and individual treatment across farms which were not taken into consideration within the model. From month to month the frequency of footbathing varied from nought to three times a week. Generally this footbathing approach was not found to have a therapeutic effect on DD compared to individual treatment, even though the model was not able to distinguish between farms footbathing and individually treating at different frequencies.

Farmers who footbathed irregularly did not appear to differentiate between prevention and treatment approaches with no strategy in place to implement treatment when necessary. An awareness of individual disease status would have been necessary in order to target treatment. On farms where footbathing is carried out in the absence of individual treatment and the disease persists, chronic cases can develop, increasing the infection pressure, increasing overall occurrence and reducing recovery. A management strategy needs to be effective at controlling the disease as well as practical to administer.

The persistent high levels of DD on UK farms indicates a failure of control prevention to minimise exposure to associated pathogens, to optimise resistance of the cows and warrants the need for aggressive treatment intervention. Best practice should distinguish between, and have in place, both proactive prevention and treatment strategies. Targeted prevention should focus on keeping feet clean, as well as regularly measuring individual lesion status, monitoring the efficacy of prevention strategies, allowing clinical cases to be identified and treated early to maximise treatment efficacy.

7.7 Conclusions

This thesis developed a system for detecting and monitoring DD in the parlour and identified the potential for thermography to be used for the generic detection of lesions, the use of which may be recommended to assess the impact of treatment interventions on the disease process. A novel ethogram to examine the impact skin and claw lesions have on a cow's behaviour was developed, and was found to be sensitive enough to identify several DD specific behavioural indicators. Locomotion scoring using a benchmark of Score 2 (lame) as the point at which to treat is not sensitive enough to identify cows with DD. A telephone survey demonstrated the nature and scope of management strategies farmers' use in an attempt to control DD.

An observational study on fifteen farms used the inspection method developed in the parlour to investigate the effect of treatment strategy on disease prevalence over a year. On these farms as herd size increased, footbathing became far less effective in maintaining a low prevalence than treating cows individually. Modelling the disease prevalence at a herd level enabled us to identify trends and relationships between management strategies. However this analysis is insufficiently detailed to investigate the impact of different levels of intervention on the dynamic progression of the disease at an individual cow level. Future research should focus on assessing the impact hygiene and conformation of the foot have on the occurrence of clinical infection and the effectiveness of treatment on the recovery and recurrence of lesions over several lactations. Of particular interest is a comparison of systemic and topical antibiotic versus topical treatment only on the recovery and reoccurrence of individual cases, and how these approaches impact on the overall long term herd level disease dynamics.

Appendices

Appendix 1: Ethogram

Event/state	Type of behaviour	Name	Definition
Continuous event	*Movement*	Lying down	Cow lies down from the standing position
		Rising	Cow rises from the lying down position
		Walking	Cow walks forward, backwards or sideways where all four limbs move at least once to a new position
		Explore	Cow examines the environment by moving towards another object to look, sniff, smell or lick it
Continuous event	*Foot*	Lifting	Cow temporary raises any limb off the ground with reluctance to place it back down on the ground
		Pawing	Cow lifts any limb and drags the pointed hoof backwards in a digging motion, striking the ground with the tip of the hoof
		Stamping	Cow brings any limb down heavily on the ground where the hoof hits the ground dead on
		Weight shifting	Cow temporarily changes weight from one limb to another
		Tip toe	One or more hind feet shift weight forwards on the toes
		Resting	Cow takes the weight off one or more limbs where weight is born on the other feet
		Swing	Cow temporarily swings one limb forwards or out to the side
		Kick	Cow strikes one foot out in the air (not towards another cow)
		Slip/stumble	Cow misses a step where one foot loses contact with the ground, due to a wet under floor surface, the foot getting caught on the floor surface or being startled
Continuous event	*Social*	Tending (bout)	Cow actively stands alongside another cow
		Jarring	Two cows' stands face on with nose to nose in an attempt to move each other out the way. One cow backs down
		Herding	Cow moves one or more cows out of the way by driving them forward from behind
		Barging	Cow uses the strength of its neck, shoulder or rear end to move another cow out of the way in a bullying manner
		Greet	Two cows meet each other by sniffing or touching muzzles in a curious, non aggressive manner
		Bulling	One cow mounts another, indicating oestrus
		Fight	Cow is frightened by another cow or another external stimulus in the surrounding environment which engages her flight response which causes her to run away
		Kick	Cow actively strikes one foot out towards another cow

Continuous event	*Grooming*	Body/head scratch	Cow repeatedly moves a part of her body or head up against an inanimate object, such as a cubicle corner or a water trough
		Self-groom (bout)	Repeated tending movement of mouth, teeth and tongue directed at own body parts, such as the udder, body, muzzle, or barrel
		Pairwise grooming (bout)	Repeated tending movement directed towards another cow
Continuous event	*Oral/anal/nasal*	Feeding (bout)	Cow is physically taking and ingesting feed
		Drinking (bout)	Cow drinks water from trough and swallows
		Ruminating (bout)	Repetitive chewing motion where each bout lasts until cow stops chewing for at least 5 seconds. This behaviour comes before and after *Regurgitation*
		Regurgitation	Contraction of the stomach followed by a controlled flow of stomach contents back into the oesophagus and mouth. This behaviour comes before and after *Ruminating*
		Elimination	Cow urinates or defecates
		Cough	Expelling of air from lungs with violent effort and characteristic noise
		Panting (bout)	Prolonged gasping for breath where cow appears under physiological strain
		Flehmen	Cow shifts head and extends neck and curls upper lip back to expose gums and clenched teeth
		Snort	Cow drives breath violently through her nose producing a loud or harsh characteristic sound
		Lick	Cow extends tongue out of mouth to pass over air, self, or external stimuli
		Sniff/smell	Cow draws up air audibly through nose or smells at an external stimuli
		Bellow	A prolonged noisy exhalation with mouth wide open
Continuous event	*Head*	Neck stretch	Cow lowers and contracts head then holds a stretched and extended neck to relieve pressure
		Flick	Cow moves neck suddenly or briskly in one fast head movement
		Roll	Cow moves head in one direction by turning it over and over repeatedly
		Turn	Head orientates in any direction away from facing forward, usually towards an external stimuli
		Bobbing	Carriage is lowered and head is moved up and down, usually as cow walks
Continuous event	*Body*	Skin twitch	Short fast spasmodic jerk of the skin at a localised area of the body
		Skin quiver	Repeated tremble of the skin with slight rapid motion
		Body rock	Cow redistributes weight by moving her body to and from backwards and forwards
		Body stretch	Cow extends body muscles before relaxing again
Continuous event	*Tail*	Swishing	Cow moves its tail from side to side in a repeated and fast action

		Flicking	Cow moves its tail to the side once in a rapid motion
Postural state	*Ear position*	Forwards	Both ears face forwards above and alongside the cow's eyes, facing in front of the cow
		Backwards	Both ears face backwards facing behind the cow
		Sideways	Both ears face sideways away from the cow
		Mixed	One cows ear faces forwards and another faces backwards
Postural state	*Eye position*	Open	Eyes fully opened and vigilant to the cow's environment
		Closed	Eye lids partly or fully closed
	Head position	Risen	Head sits higher than the withers
		Level	Head sits level with the withers
		Down	Head sits lower than the withers
	Back position	Flat	Spine lays flat and straight, perpendicular the floor
		Arched	Spine is visible arched
	Leg position	Even weight	Cow bears weight evenly on all four limbs
		Resting limb	Cow rests one particular limb off the floor, where weight is born on the other 3 limbs
	Tail position	Relaxed	Tail hangs freely and vertically from the body base
		Tucked	Tail is held against the rump between the hind legs
		Out	Tail is held out away from the rump in a fixed position
		Swishing	Tail flicks from side to side in a continuous motion across the hindquarters
	Body position	Laid down	Cow lies down on the sternum with limbs folded underneath her body
		Standing up	Cow is in a stationary upright position
		Walking	Cow walks forward, backwards or sideways where all four limbs move at least once to a new position

Appendix 2: Data collection sheet for event behaviours

Farm: Time: Date:

BODY MOVEMENT				BODY					
Lying down	Rising up	Walking forwards	Walking backwards	Skin twitch	Skin quiver	Body rock	Body stretch	Stomach retch	Elimination

SOCIAL								GROOMING		
Tending	Jarring	Herding	Barge	Greet	Bulling	Flight	Kick	Body/head scratch	Self groom	Pairwise grooming

LIMB MOVEMENT																			
Tip toes				Resting feet				Limb swing				Limb Kick				Slip/stumble			
FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR

LIMB MOVEMENT																	
Stamping				Pawing				Shaking				Lifting foot				Weight Shifting	
FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	FL	FR	HL	HR	Front	Hind

HEAD						TAIL	
Neck stretch	Explore environment	Bobbing	Flick	Roll	Turn	Swishing	Flick

ORAL/VOCAL									
Sniff/smell	Lick	Snort	Cough	Pant	Flehmen	Feeding	Ruminate	Drink	Bellow

Appendix 3: Data collection sheet for postural behaviours Farm: Time: Date

TIME	EARS	EYES	HEAD	BACK	LIMB	TAIL	BODY
1	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weigh ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
2	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
3	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐FR ☐ HL ☐HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
4	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
5	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
6	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
7	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
8	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
9	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐
10	Forwards ☐ Backwards ☐ Sideways ☐	Open ☐ Closed ☐	Risen ☐ Level ☐ Down ☐ Turned ☐	Flat ☐ Arched ☐	Even weight ☐ FL ☐ FR ☐ HL ☐ HR ☐	Relaxed ☐ Tucked ☐ Swish ☐ Out ☐	Standing ☐ Laid down ☐

References

Archer, S., Bell, N., Huxley, J., 2010. Lameness in UK dairy cows: a review of the current status. In Practice, 32, 492-504.

Amory, J.R., Barker, Z.E., Wright, J.L., Mason, S.A., Blowey, R.W., Green, L.E., 2008. Associations between sole ulcer, white line disease and digital dermatitis and the milk yield of 1824 dairy cows on 30 dairy cow farms in England and Wales from February 2003-November 2004. Preventive Veterinary Medicine, 83, 381-391.

Argaez Rodriguez, F., Hird, D.W., Hernandez de Anda, J., Read, D.H., Rodriguez Lainz, A., 1997. Papillomatous digital dermatitis on a commercial dairy farm in Mexico: incidence and effect on reproduction and milk production. Preventive Veterinary Medicine 32, 275-286.

Armitage, C.J., Christian, J., 2003. From attitudes to behaviour: Basic and applied research on the theory of planned behaviour. Current Psychology, 22, 187-195.

Bassett. H.F., Monaghan, M.L., Lenhan, P., Doherty, M.L. Carter, M.E., 1990. Bovine digital dermatitis. Veterinary Record, 126, 164-165.

Barker, Z.E., Leach, K.A., Whay, H.R., Bell, N.J. Main, D.C.J., 2010. Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales. Journal of Dairy Science, 93, 932-941.

Bell, N.J., 2006. The Alleviation and Prevention of Lameness in Dairy Heifers. Department of Clinical Veterinary Science. Thesis, Doctorate of Philosophy, University of Bristol.

Bell, N.J., 2011. A case report assessing one potential method or eradicating digital dermatitis from a group of Holstein Friesian maiden heifers. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 120.

Bell, N.J., Bell, M.J., Knowles, T.G., Whay, H.R., Main, D.C.J., Webster, A.J.F., 2009. The development, implementation and testing of a lameness control programme based on HACCP principles and designed for heifers on dairy farms. The Veterinary Journal, 180, 178-188.

Bergsten, C.J., Hultgren, J., Hillstrom, A., 2007. Using copper sulphate, peracetic acid or a combination of both in foot bath for the control of digital dermatitis and heel horn erosion in dairy cows. In: Proceedings of the 13th International Congress in Animal Hygiene, Tartu, Estonia.

Berry, R.J., Reed, B.A., Maas, J.P., Schechter, A., 1996. The efficacy of five topical spray treatments for control of papillomatous digital dermatitis in dairy herds. In, Proceedings of the 29th Annual Conference of the American Association of Bovine Practitioners, San Diego, USA, pp.188.

Berry, S.L., Read, D.H., 1999. Recurrence of papillomatous digital dermatitis (footwarts) in dairy cows after treatment with lincomycin HCL or oxytetracycline HCI. Journal of Dairy Science, 82, 34.

Berry, R.J., Kennedy, A.D., Scott, S.L., Kyle, B.L., Schaefer, A.L., 2003. Daily variation in the udder surface temperature of dairy cows measured by infrared thermography: potential for mastitis detection. Canadian Journal of Animal Science, 83, 687-693.

Berry, S.L., Read, D.H., Walker, R.L., Famula, T.R., 2010. Clinical, histologic, and bacteriologic findings in dairy cows with digital dermatitis (footwarts) one month after topical treatment with lincomycin hydrochloride or oxytetracycline hydrochloride. Journal of the American Veterinary Medical Association, 237, 555-560.

Blowey, R.W., 1987. Digital dermatitis in dairy cattle. Veterinary Record, 121, 311.

Blowey, R.W., Sharp, M.W., 1988. Digital dermatitis in dairy cattle. Veterinary Record, 122, 505-508.

Blowey, R.W., 1992. Diseases of the bovine digit. Part 1. Description of common lesions. In Practice, 14, 85-90.

Blowey, R.W., Done, S.H., Cooley, W., 1994. Observations on the pathogenesis of digital dermatitis in cattle. Veterinary Record, 135, 115-117.

Blowey, R.W., 2000. Control of digital dermatitis. Veterinary Record, 146, 295.

Blowey, R.W., 2005. Factors associated with lameness in dairy cattle. In Practice, 27, 154-162.

Blowey, R., 2007. Digital dermatitis – Research and control. Irish Veterinary Journal, 60, 102-106.

Boe, K. E., Faerevik, G., 2003. Grouping and social preferences in calves, heifers, and cows. Applied Animal Behaviour Science, 80, 175-190.

Borges, J.B.J., Pitombo, C.A., Santiago, S.S., Ribeiro, P.N., Ronconi, M.A., 1992. Incidence of foot diseases in dairy cattle under different management systems, Arquivos da Escola de Medicina Veterinaria da Universidade Federal da Bahia, 15, 34-42.

Borgmann, I.E., Bailey, J., Clark, E.G., 1996. Spirochete-associated bovine digital dermatitis. Canadian Veterinary Journal, 37, 35-37.

Boyle, L.A., Mee, J.F., Kiernan, P.J., 2007. The effect of rubber versus concrete passageways in cubicle housing on claw health and reproduction of pluriparous dairy cows. Applied Animal Behaviour Science, 106, 1-12.

Britt, J.S., Gaska, J., Garrett, E.F., Konkle, D., Mealy, M., 1996. Comparison of topical application of three products for treatment of papillomatous digital dermatitis in dairy cattle. Journal of the American Veterinary Medical Association, 209, 1134-1136.

Brown, C.C., Kilgo, P.D., Jacobsen, K.L., 2000. Prevalence of papillomatous digital dermatitis among culled adult cattle in the southeastern United States. American Journal of Veterinary Research, 61, 928-930.

Burn, C.C., Pritchard, J.C., Whay, H.R., 2009. Observer reliability for working equine welfare assessment: problems with high prevalence of certain results. Animal Welfare, 18, 177-187.

Carter, S., Evans, N., Timofte, D., Brown, J., Blowey, R., Murray, R., Birtles, R., Hart, T., 2009. Dermatitis – Microbial Aetiopathogenesis approaches providing opportunities for treatment. In: Proceedings of the Cattle Lameness Conference, Sutton Bonnington, University of Nottingham, pp. 9-18.

Cheli, R., Mortellaro, C.M., 1974. Digital dermatitis in cattle. In: Proceedings of the 8th International Meeting on Diseases of Cattle, Milan, Italy, pp. 208-213.

Choi, B.K., Nattermann, H., Grund, S., Haider, W., Gobel, U.B., 1997. Spirochetes from digital dermatitis lesions in cattle are closely related to treponemes associated with human periodontitis. International Journal of Systematic Bacteriology, 47, 175-181.

Clarkson, M.J., Downham, D.Y., Faull, W.B., Hughes, J.W., Manson, F.J., Merritt, J.B., Murray, R.D., Russell, W.B., Sutherst, J.E., Ward, W.R., 1996. Incidence and prevalence of lameness in dairy cattle. Veterinary Record, 138, 563-567.

Colak, A., Polat, B., Okumus, Z., Kaya, M., Yanmaz, L.E., Hayirli, A., 2008. Short Communication: Early detection of mastitis using infrared thermography in dairy cows. Journal of Dairy Science, 91, 4244-4248.

Collighan, R.J., Naylor, R.D., Martin, P.K., Cooley, B.A., Buller, N. Woodward, M.J., 2000. A spirochete isolated from a case of severe virulent ovine foot disease is closely related to a treponeme isolated from human periodontitis and bovine digital dermatitis. Veterinary Microbiology, 74, 249-257.

Cook, N.B., Rieman, J., Burgi, K., Ward, A., Gomez, A., Dopfer, D., Socha, M., 2011. Footrot: New technology – new solutions behavioral observations on hootbath design. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 1.

Cooper, M.D., Arney, D.R., Phillips, C.J.C., 2007. Two- or four-hour lying deprivation on the behavior of lactating dairy cows. Journal of Dairy Science, 90, 1149-1158.

Cornelisse, J.L., Peterse, D.J., Toussaint Raven, E., 1981. A digital disorder in dairy cattle. Dermatitis digitalis? Tijdschrift voor Diergeneeskunde, 106, 452-455.

Cramer, G., Lissemore, K.D., Guard, C.L., Leslie, K.E., Kelton, D.F., 2008. Herd level risk factors for seven different foot lesions on Ontario Holstein cattle housed in tie stalls or free stalls. Journal of Dairy Science, 92, 1404-1411.

Cruz, C., Driemeier, D., Cerva, C., Corbellini, L.G., 2000. Clinical and epidemiological aspects of bovine digital lesions in southern Brazil. Arquivo Brasileiro de Medicina Veterinaria e Zootecnia, 52, 654-657.

Defra, 2009. Defra Farming Statistics Report (June Agricultural Survey 2008). https://statistics.defra.gov.uk/esg/publications/fps/FPS2008.pdf (accessed 19th May, 2009).

Demirkan, I., Carter, S.D., Murray, R.D., Blowey, R.W., Woodward, M.J., 1998. The frequent detection of a treponeme in bovine digital dermatitis by immunocytochemistry and polymerase chain reaction. Veterinary Microbiology, 60, 285-292.

Dhawi, A., Hart, C.A., Demirkan, I., Davies, I.H., Carter, S.D., 2005. Bovine digital dermatitis and severe virulent ovine foot rot: A common spirochaetal pathogenesis. The Veterinary Journal, 169, 232-241.

Dopfer, D., 1994. Epidemiological investigations of digital dermatitis on two dairy farms. Thesis, Masters of Science, University of Hannover.

Dopfer, D., Koopmans, A., Meijer, F.A., Szakall, I., Schukken, Y.H., Klee, W., Bosma, R. B., Cornelisse, J.L., van Asten, A.J.A.M., ter Huurne, A.A.H.M., 1997. Histological and bacteriological evaluation of digital dermatitis in cattle, with special reference to spirochetes and Campylobacter faecalis. Veterinary Record, 140, 620-623.

Dopfer, D., Lopez-Benavides, M., Buchalova, M., Mateus, C., Cook, N.B., Dusick, A.F., Hemling, T.C., Socha, M., Read, D. and Gomez, A., 2011. Clinical, histopathological, and microbiological cure of acute digital dermatitis lesions and the influence of topical treatments upon cure. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 25.

Ettema, J.F., Capion, N., Hill, A.E., 2007. The association of hoof lesions at claw trimming with test-day milk yield in Danish Holsteins. Preventive Veterinary Medicine, 79, 224-243.

Ettema, J.F., Ostergaard, S., Kristensen, A.R., 2009. Estimation of probability for the presence of claw and digital skin diseases by combining cow- and herd-level information using a Bayesian network. Preventive Veterinary Medicine, 92, 89-98.

Field, A., 2009. Correlation. In: Discovering Statistics using SPSS. SAGE Publications Limited, London, UK, pp. 166-196.

Frankena, K., Stassen, E.N., Noordhuizen, J.P., Goelema, J., Schipper, J., Smelt, H. Romkema, H., 1991. Prevalence of lameness and risk indicators for dermatitis digitalis (Mortellaro's disease) during pasturing and housing of dairy cattle. In: Proceedings of a meeting of the Society of Veterinary Epidemiology and Preventive Medicine, London, UK, pp. 107-118.

Frankena, K., Klaas, van Keulen, K.A.S., Noordhuizen, J.P., Noordhuizen-Stassen, E.N., Gundelach, J., de Jong, D.J., Saedt, I., 1993. A cross-sectional study of prevalence and risk factors of dermatitis interdigitalis in female dairy calves in the Netherlands. Preventive Veterinary Medicine, 17, 137-144.

Fregonesi, J.A., Leaver, J.D., 2001. Behaviour, performance and health indicators of welfare for dairy cows housed in straw yard or cubicles systems. Livestock production science, 68, 205-216.

Galindo, F., Bloom, D.M., 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Research in Veterinary Science, 69, 75-79.

Green, L.E., Hedges, V.J., Schukken, Y.H., Blowey, R.W., Packington, A.J., 2002. The impact of clinical lameness on the milk yield of dairy cows. Journal of Dairy Science, 85, 2250-2256.

Greenough, P.R., MacCallum, F.J., Weaver, A.D., 1981. Lameness in Cattle 2nd Ed. John Wright and Sons Limited, Bristol, UK.

Grund, S., Nattermann, H., Horsch, F., 1995. Electron microscopic detection of spirochetes in dermatitis digitalis of cattle. Zentralblad Veterinarmedizin B, 42, 533-42.

Hanna, P., Lofstedt, J., Duivenvoorden, P., 1994. Prince Edward Island. Papillomatous digital dermatitis in a Canadian dairy herd. Canadian Veterinary Journal, 35, 657.

Hartog, B.J., Tap, S.H., Pouw, H.J., Poole, D.A., Laven, R.A., 2001. Systemic bioavailability of erythromycin in cattle when applied by footbath. Veterinary Record, 148, 782-783.

Head, M.J., Dyson, S., 2001. Talking the temperature of equine thermography (editorial). The Veterinary Journal, 162, 166-167.

Hedges, J., Blowey, R.W., Packington, A.J., O'Callaghan, C.J., Green, L.E., 2001. A longitudinal field trial of the effect of biotin on lameness in dairy cows. Journal of Dairy Science, 84, 1969-1975.

Hernandez, J., Shearer, J.K., 2000. Efficacy of oxytetracycline for treatment of papillomatous digital dermatitis lesions on various anatomic locations in dairy cows. Journal of the American Veterinary Medical Associations, 218, 1288-1290.

Hill. A.E., Green, A.L., Wagner, B.A., Dargatz, D.A., 2009. Relationship between herd size and annual prevalence of and primary antimicrobial treatments for common diseases on dairy operations in the United States. Preventive Veterinary Medicine, 88, 264-277.

Holzhauer, M., Hardenberg, C., Bartels, C.J., Frankena, K., 2006. Herd- and cow-level prevalence of digital dermatitis in the Netherlands and associated risk factors. Journal of Dairy Science, 89, 580-588.

Holzhauer, M., Bartel, C.J.M., Dopfer, D., van Schaik, G., 2007. Clinical course of digital dermatitis lesions in an endemically infected herd without preventive herd strategies. The Veterinary Journal, 177, 222-230.

Holzhauer, M., Dopfer, D., De Boer, J., van Schaik, G., 2008. Effects of different intervention strategies on the incidence of papillomatous digital dermatitis in dairy cows. Veterinary Record, 162, 41-46.

Hovinen, M., Siivonen, J., Taponen, S., Hanninen, L., Pastell, M., Aisla, A.M., Pyorala, S., 2008. Detection of Clinical Mastitis with the Help of a Thermal Camera. Journal of Dairy Science, 91, 4592-4598.

Hurnik, J.F., Webster, A.B., De Boer, S., 1985. An investigation of skin temperature differentials in relation to oestrus in dairy cattle using a thermal infrared scanning technique. Journal of Animal Science, 61, 1095-1102.

Kaler, J., George, T.R.N., Green, L.E., 2009. A Longitudinal Study of Locomotion, Interdigital Dermatitis and Footrot in Sheep. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 84-87.

Kaler, J., Medley, G.F., Grogono-Thomas, R., Wellington, E.M.H., Calvo-Bado, L.A., Wassink, G.J., King, E.M., Moore, L.J., Russell, C., Green, L.E., 2010. Factors associated with changes of state of foot conformation and lameness in a flock of sheep. Preventative Veterinary Medicine, 97, 237-244.

Kendall, P.E., Webster, J.R., 2009. Season and physiological status affects the circadian body temperature rhythm of dairy cows. Livestock science, 125, 155-160.

Kimura, Y., Takahashi, M., Matsumoto, N., Tsukuda, H., Satoh, M., Ohkawara, K., Kanoe, M., Gotoh, N., Kubo, M., Aoki, O., Hataya, M., 1993. Verrucose dermatitis and digital papillomatosis in dairy cows. Journal of Veterinary Medicine, Japan, 46, 899–906.

Koniarova, I., Orsag, A., Ledecky, V., 1993. The role of anaerobes in the occurrence of digital digitalis-et-interdigitalis in cattle. Veterinarni Medicina, 38, 589-596.

Kyllar, V., Ryjacek, J., Sterc, J., Cech, S., 1985. Occurrence and treatment of digital dermatitis in cattle. Veterinarni Medicina, 30, 585-594.

Landis, J.R., Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics, 33, 159-174.

Laven, R.A., 1999. The environment and digital dermatitis. Cattle Practice, 7, 349-354.

Laven, R.A., Proven, M.J., 2000. Use of an antibiotic footbath in the treatment of bovine digital dermatitis. Veterinary Record, 147, 503-506.

Laven, R.A., 2001. Control of digital dermatitis in cattle. In Practice, 23, 336-341.

Laven, R.A., Hunt, H., 2001. Comparison of valnemulin and lincomycin in the treatment of digital dermatitis by individually applied topical spray. Veterinary Record, 149, 302-303.

Laven, R.A., 2003. Desktop review into the management and treatment of digital dermatitis, Technical Report 02/T3/07, MDC.

Laven, R.A., Lawrence, K.R., 2006. An evaluation of the seasonality of veterinary treatments for lameness in UK dairy cattle. Journal of Dairy Science, 89, 3858-3865.

Laven, R.A., Logue, D.N., 2006. Treatment strategies for digital dermatitis for the UK, The Veterinary Journal, 171, 79-88.

Leach, K.A., Dippel, S., Huber, J., March, S., Winckler, C., Whay, H.R., 2009. Assessing lameness in cows kept in tie-stalls. Journal of Dairy Science, 92, 1567-1574.

Leach, K.A., Whay, H.R., Maggs, C.M., Barker, Z.E., Paul, E.S., Bell, A.K., Main, D.C.J., 2010. Working towards a reduction in cattle lameness: 1. Understanding barriers to lameness control on dairy farms. Research in Veterinary Science, 89, 311-317.

Logue, D.N., Offer, J.E., Laven, R.A., Ellis, W.A., 2005. Digital dermatitis – The aetiological soup. The Veterinary Journal, 170, 12-13.

Losinger, W.C., 2006. Economic impacts of reduced milk production associated with papillomatous digital dermatitis in dairy cows in the USA. Journal of Dairy Research, 73, 244-256.

Manske, T., 2002. Hoof lesions and lameness in Swedish dairy cattle. Thesis, Doctorate of Philosophy, Swedish University of Agricultural Sciences.

McLennan, M.W., McKenzie, R.A., 1996. Digital dermatitis in a Friesian cow. Australian Veterinary Journal, 74, 314-315.

Milinovich, G.J., Turner, S.A., McLennan, M.W., Trott, D.J., 2004. Survey for papillomatous digital dermatitis in Australian dairy cattle. Australian Veterinary Journal, 82, 20-24.

Mononen, J., 2008. An Ethogram is more than a mere research tool. In: Proceedings of the 15th Symposium and 7th Conference on Lameness in Ruminants, Kuopio, Finland, pp. 19-23.

Mortellaro, C., Cheli, R., Raven, E., Cornelisse, J., Toussaint Raven, E., 1985. Digital dermatitis in cattle. Pro Veterinario, 3, 11.

Munsell, B., 2004. The use of infrared thermography to determine surface temperature of the coronary band of dairy cows as a tool for lameness detection. PhD thesis, Michigan State University.

Murray, R.D., Downham, D.Y., Clarkson, M.J., Faull, W.B., Hughes, J.W., Manson, F.J., Merritt, J.B., Russell, W.B., Sutherst, J.E., Ward, W.R., 1996. Epidemiology of lameness in dairy cattle: description and analysis of foot lesions. The Veterinary Record, 138, 586-591.

Murray, R.D., Downham, D.Y., Demirkan, I., Carter, S.D., 2002. Some relationships between spirochaete infections and digital dermatitis in four UK dairy herds. Research in Veterinary Science, 73, 223-30.

Nielsen, B.H., Thomsen, P.T., Sorensen, J.T., 2009. A study of duration of digital dermatitis lesions after treatment in a Danish dairy herd. Acta Veterinaria Scandinavica, 51, 27-31.

Nielsen, B.H., Kaler, J., Thomsen, P.T., Green, L., 2011. Heterogeneity of lactating cows to digital dermatitis. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 8.

Nikkah, A., Plaizier, J.C., Einarson, M.S., Berry, R.J., Scott, S.L., Kennedy, A.D., 2005. Short Communication: Infrared Thermography and Visual Examination of Hooves of Dairy Cows in two Stages of Lactation. Journal of Dairy Science, 88, 2749-2753.

Nowrouzian, I., Zareii, S., 1998. Comparison of two application forms of lincomycin HCI for group treatment of digital dermatitis in dairy cows. In: Proceedings of the 10th International Symposium on lameness in Ruminants, Lucerne, Switzerland, pp. 287-288.

Nourouzian, I., Radgohar, I., 2011. Retrospective study of the correlation between hygiene scores and the prevalence of papillomatous digital dermatitis in dairy cows. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 16.

Nuss, K., 2006. Footbaths: The solution to digital dermatitis? The Veterinary Journal, 171, 11-13.

Nutter, W.T., Moffitt, J.A., 1990. Digital dermatitis control. Veterinary Record, 126, 200-201.

O'Callaghan, K.A., 2002. Lameness and associated pain in cattle – challenging traditional perceptions. In Practice, 24, 212-219.

Offers, J.E., Logue, D.N., McNulty, D., 2000. Observation of lameness, hoof conformation and development of lesions in dairy cattle over four lactations. The Veterinary Record, 147, 105-109.

Onyiro, O.M., Andrews, L.J., Brotherstone, S., 2008. Genetic Parameters for Digital Dermatitis and Correlations with Locomotion, Production, Fertility Traits, and Longevity in Holstein Friesian Dairy Cows. Journal of Dairy Science, 91, 4037-4046.

Palmer, S.E., 1981. Use of the portable infrared thermometer as a means of measuring limb surface temperature in the horse. American Journal of Veterinary Research, 42, 105-108.

Purohit, R.C., McCoy, M.D., 1980. Thermography in the diagnosis of inflammatory processes in the horse. American Journal Of Veterinary Research, 41, 1176-72.

Rainwater-Lovett, K., Pacheco, J.M., Packer, C., Rodriguez, L.L., 2009. Detection of Foot-and-mouth disease virus infected cattle using infrared thermography. The Veterinary Journal, 180, 317-324.

Read, D.H., Walker, R.L., Castro, A.E., Sundberg, J.P., Thurmond, M.C., 1992. An invasive spirochaete associated with interdigital papillomatous of dairy cattle. Veterinary Record, 130, 59-60.

Read, D.H., Walker, R.L., 1996. Experimental transmission of papillomatous digital dermatitis (footwarts) in cattle. Veterinary Pathology, 33, 607.

Read, D.H., Walker, R.L., 1998. Papillomatous digital dermatitis (footwarts) in California dairy cattle: Clinical and gross pathologic findings. Journal of Veterinary Diagnostic Investigation, 10, 67-76.

Rebhun, W.C., Payne, R.M., King, J.M., Wolfe, M., Begg, S.N., 1980. Inter-digital papillomatosis in dairy cattle. Journal of the American Veterinary Medical Association, 177, 437-440.

Rodriguez-Lainz, A., Hird, D.W., Carpenter, T.E., Read, D.H., 1996. Case-control study of papillomatous digital dermatitis in southern California dairy farms. Preventive Veterinary Medicine, 28, 117-131.

Rodriguez-Lainz, A., Melendez-Retamal, P., Hird, D.W., Read, D.H., 1998. Papillomatous digital dermatitis in Chilean dairies and evaluation of a screening method. Preventive Veterinary Medicine, 37, 197-207.

Rodriguez-Lainz, A., Melendez-Retamal, P., Hird, D.W., Read, D.H., Walker, R.L., 1999. Farm- and host-level risk factors for papillomatous digital dermatitis in Chilean dairy cattle. Preventative Veterinary Medicine, 42, 87-97.

Roztocil, V., Ulman, L., Rusek, T., Berankova, E., 1988. Incidence and control of digital dermatits of cattle kept on large dairy cattle units with open successive herd grazing. Monatshefte fuer Veterinaermedizin, 43, 536-539.

Rutter, B., 1989. Metacresolsulfonic acid in the treatment of bovine interdigital dermatitis. Veterinaria Argentina, 6, 258-260.

Rutter, B., Ierace, A., Bottaro, A., 2001. Digital dermatitis in Friesian cattle in Argentina, and its treatment with cefquinone. Revista de Medicina Veterinaria Buenos Aires, 82, 242-243.

Salam, D., El.Fadel, M., 2008. Mobility and availability of copper in agricultural soils irrigated from water treated with copper sulphate algaecide. Water Air and Soil Pollution, 195, 3-13.

Schaefer, A.L., Cook, N., Tessaro, S.V., Deredt, D., Desroches, G., Dubeski, P.L., Tong, A.K.W., Godson, D.L., 2004. Early detection and prediction of infection using infrared thermography. Canadian Journal of Animal Science, 84, 73-80.

Scott, E.M., Fitzpatrick, J.L., Nolan, A.M., Reid, J., Wiseman, M.L., 2003. Evaluation of welfare state based on interpretation of multiple indices. Animal Welfare, 12, 457-468.

Scott, S.L., Schaefer, A.L., Tong, A.K.W., Lacasse, P., 2000. Use of infrared thermography for early detection of mastitis in dairy cows. Canadian Journal of Animal Science, 80, 764-765.

Shearer, J.K., Hernandez, J., 2000. Efficacy of two modified nonantibiotics formulations (Victory) for treatment of papillomatous digital dermatitis in dairy cows. Journal of Diary Science, 83, 741-745.

Silva, L.A., Silva, C.A., Borges, J.R., Fioravanti, M.C., Borges, G.T., Atayde, I.B., 2005. A clinical trial to assess the use of sodium hypochlorite and oxytetracycline on the healing of digital dermatitis lesions in cattle. Canadian Veterinary Journal, 46, 345-348.

Sim, J., Wright, C.C., 2005. The Kappa Statistic in Reliability Studies: Use, Interpretation and Sample Size Requirements. Physical Therapy, 85, 257-268.

Singh, S.S., Ward, W.R., Lautenbach, K., Murray, R.D., 1993. Behaviour of lame and normal dairy cows in cubicles and in a straw yard. The Veterinary Record, 133, 204-208.

Sogstad, A.M., Osteras, O., Fjeldaas, T., 2006. Bovine claw and limb disorders related to reproductive performance and production diseases. Journal of Dairy Science, 89, 2519-2528.

Somers, J.G.C.J., Frankena, K., Noordhuizen-Stassen, E.N., Metz, J.H.M., 2003. Prevalence of claw disorders in Dutch dairy cows exposed to several floor systems. Journal of Dairy Science, 86, 2082-2093.

Somers, J., 2004. Claw disorders and disturbed locomotion in dairy cows: the effect of floor systems and implications for animal welfare. Thesis, Doctorate of Philosophy, University of Utrecht.

Somers, J.G.C.J., Frankena, K., Noordhuizen-Stassen, E.N., Metz, J.H.M., 2005a. Risk factors for digital dermatitis in dairy cows kept in cubicle houses in The Netherlands. Preventive Veterinary Medicine, 71, 11-21.

Somers, J.G.C.J., Schouten, W.G.P., Frankena, K., Noordhuizen-Stassen, E.N., Metz, J.H.M., 2005b. Development of claw traits and claw lesions in dairy cows kept on different floor systems. Journal of Dairy Science, 88, 110-120.

Stevancevic, M., Toholj, B., Lako, B., Potkonjak, A., Kuljaca, V., 2009. Study of the effectiveness of topical application of antiseptics in the therapy of digital dermatitis in dairy cattle. Acta Veterinaria-Beograd, 59, 437-455.

Stewart, M., Webster, J.R., Schaefer, A.L., Cook, N.J., Scott, S.L., 2005. Infrared thermography as a non-invasive tool to study animal welfare, Animal Welfare, 14, 319-325.

Telezhenko, E., Bergsten, C., 2005. Influence of floor type on the locomotion of dairy cows. Applied Animal Behaviour Science, 93, 183-197.

Teixeira, A.G.V., Machado, V.S., Caixeta, L.S., Pereira, R.V., Bicalho, R.C., 2010. Efficacy of formalin, copper sulphate, and a commercial footbath product in the control of digital dermatitis. Journal of Dairy Science, 93, 3628-3634.

Thomsen, P.T., Klaas, I.C., Bach, K., 2008. Short communication: Scoring of digital dermatitis during milking as an alternative to scoring in a hoof trimming chute. Journal of Dairy Science, 91, 4679-4682.

Thomsen, P.T., Kjaer Ersbolll, A., Hemling, T.C., Tind Sorensen, J., 2011. Automatic washing of hooves can help cure digital dermatitis in dairy cows. In: Proceedings of the 16th International Symposium and 8th Conference on Lameness in Ruminants, Rotorua, New Zealand, pp. 29.

Trott, D.J., Moeller, M.R., Zuerner, R.L., Goff, J.P., Waters, W.R., Alt, D.P., Walker, R.L., Wannemuehler, M.J., 2003. Characterization of *Treponema phagedenis*-like spirochetes isolated from papillomatous digital dermatitis lesions in dairy cattle. Journal of Clinical Microbiology, 41, 2522-2529.

Turner, T.A., Purohit, R.C., Fessler, J.F., 1986. Thermography: a review in equine medicine. Equine Veterinary Science, 5, 8-10.

Turner, T.A., 1989. Diagnosis and treatment of the navicular syndrome in horses. Veterinary Clinics of North America: Large Animal Practice, 5, 131-144.

Turner, T.A., 1991. Thermography as an aid to the clinical lameness evaluation. Veterinary Clinics of North America: Equine Practice, 7, 311-338.

Van Amstel, S.R., Van Vuuren, S., Tutt, C.L., 1995. Digital dermatitis: report of an outbreak. Journal of the South African Veterinary Association, 66, 177-181.

Van Hoogmoed, L.M., Snyder, J.R., Allen, K.A., Waldsmith, J.D., 2000. Use of thermography to detect performance enhancing techniques in horses. Equine Veterinary Education, 12, 132-138.

Van Hoogmoed, L.M., Snyder, J.R., 2002. Use of Infrared Thermography to Detect Injections and Palmar Digital Neurectomy in Horses. The Veterinary Journal, 164, 129-141.

Vink, D.W., 2006. Investigating the epidemiology of Bovine Digital Dermatitis: causality, transmission and infection dynamics. Thesis, Doctorate of Philosophy, University of Liverpool.

Walker, R.L., Read, D.H., Loretz, K.J., Nordhausen, R.W., 1995. Spirochetes isolated from dairy cattle with papillomatous digital dermatitis and interdigital dermatitis. Veterinary Mircobiology, 47, 343-355.

Wassink, G.J., George, T.R.N., Kaler, J., Green, L.E., 2010. Footrot and interdigital dermatitis in sheep: Farmer satisfaction with current management, their ideal management and sources used to adopt new strategies. Preventive Veterinary Medicine, 96, 65-73.

Weaver, A.D., Andersson, L., De Laistre Banting, A., Demerzis, P.N., Knezevic, P.F., Peterse, D.J. and Sankovic, F., 1981. Review of disorders of the ruminant digit with proposals for anatomical and pathological terminology and recording. Veterinary Record, 108, 117-120.

Wells, S.J., Trent, A.M., Marsh, W.E., McGovern, P.G., Robinson, R.A., 1993. Individual cow risk factors for clinical lameness in lactating dairy cows. Preventive Veterinary Medicine, 17, 95-109.

Wells, S.J., Garber, L.P., Wagner, B.A., 1999. Papillomatous digital dermatitis and associated risk factors in US dairy herds. Preventative Veterinary Medicine, 38, 11-24.

Wemelsfelder, F., Hunter, T.E.A., Mendl, M.T., Lawrence, A.B., 2001. Assessing the 'whole animal': a free choice profiling approach. Animal Behaviour, 62, 209-220.

Whay, H.R., Waterman, A.E., Webster, A.J.F., 1997. Associations between locomotion, claw lesions and nociceptive threshold in dairy heifers during the peri-partum period. The Veterinary Journal, 154, 155-161.

Whay, H.R., Waterman, A.E., Webster, A.J.F., O'Brien J.K., 1998. The influence of lesion type on the duration of hyperalgesia associated with hindlimb lameness in dairy cattle. Veterinary Journal, 156, 23–29.

Whay, H.R., 2002a. Locomotion scoring and lameness detection in dairy cattle. In Practice, 444-449.

Whay, H.R., Main, D.C.J., Green, L.E., Webster, A.J.F., 2002b. Farmer perception of lameness prevalence. In: Proceedings of the 12th International Symposium on Lameness in Ruminants, Orlando, Florida, pp. 355-358.

Whay, H.R., Bell, M.J., Main, D.C.J., 2004. Validation of Lame Limb Identification through Thermal Imaging. In: Proceedings of the 13th International Symposium and 5th Conference on Lameness in Ruminants, Slovenia, pp. 237-238.

Winkler, C., Willen, S., 2001. The reliability and repeatability of a lameness scoring system for use as an indicator of welfare in dairy cattle. Acta Agriculturae Scandinavica Section A – Animal Science, 30, 103-107.

Zemlijic, B., 2004. Influence of footbathing on prevalence of digital dermatitis after introduction of diseased animals into healthy dairy herds. In: Proceedings of the 13th Symposium on Lameness in Ruminants, Maribor, Slovenia, pp. 145-147.